# Nature's Sure Connected

A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

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### Funding

This project was funded by the National Lottery Heritage Fund.


### Project partners




### Suggested citation:

Tinsley-Marshall, P.J., Riggs, A., Skilbeck, A., Ball, L. & Still, R. (2021) Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation. Kent Wildlife Trust.

# Contents







# Executive Summary


- Landscape-scale conservation is the combined contribution of multiple actions, on multiple sites, and by multiple stakeholders, to the resilience of ecological networks. This results in a complex matrix of interventions and policies in space and time. Monitoring the outcomes of landscape-scale conservation therefore presents significant challenges to the individuals and organisations involved in its delivery.
- Monitoring of site-scale outcomes is well-established and best practice available and adopted. Landscape-scale monitoring is in its infancy by comparison. The absence of common standards and approaches reflects both the infancy of landscape-scale conservation and the  scale and complexity of the challenge.
- Nature's Sure Connected sought to address these challenges by consulting widely with a community of conservation practitioners to gather expertise and information on their needs from landscape-scale monitoring. The project reviewed and analysed existing landscape-scale monitoring approaches, generated consensus on priorities and principles, and developed partnerships to design and test sustainable monitoring approaches. This informed the development and testing of a monitoring framework and practical approaches to landscape-scale monitoring.
- The project developed a practical framework structured around a series of logical steps to inform the creation of monitoring objectives and programmes. This framework is set out in Chapter 3 and signposts guidance, outputs and case studies developed by the project. Guidance is offered around defining landscape parameters, key attributes of monitoring programmes, landscape monitoring themes, priority themes and questions for landscape-scale monitoring to address, defining and articulating monitoring objectives, and criteria for selecting landscape indicator species.
- The five key themes prioritised by stakeholders for the project to address were: 1) more sites and larger areas managed positively for conservation, 2) better land management and habitat quality, 3) joined-up spaces for nature and better-connected landscapes, 4) biodiversity trend assessment at landscape-scale, and 5) ecosystem function, its conservation and resilience. The input of stakeholders fed into the development of each approach.
- Chapter 4 details a tool to facilitate data capture and monitoring of the area of land managed positively for conservation by multiple stakeholders at county and landscape-scales and provides a blueprint for others to replicate the approach.
- Chapter 5 details the steps taken by the project to develop drone-based remote sensing capabilities within Kent Wildlife Trust, to facilitate a cost-to-scale effective approach to monitoring attributes of habitat quality at landscape-scale. A set of outputs provide practical guidance to help others to develop these capabilities.
- Chapter 6 presents a dual approach to monitoring connectivity though modelling potential connectivity predicted by spatial data on habitats and using a novel field survey method developed by the project to detect functional connectively; evidence of species permeating landscapes. Outputs provide guidance for selecting connectivity modelling approaches, and case studies to aid others in adopting these approaches.
- Chapter 7 focuses on the challenge of resourcing survey effort at landscape-scales to assess species trends by presenting an efficient distribution mapping approach based on using simple presence/absence data as a proxy for abundance. Recent advances in statistical techniques that allow the use of existing structured and opportunistic survey data to assess trends at sub-national scales are review and opportunities discussed.
- Chapter 8 reviews the wealth of ecosystem services provided by landscapes and presents a pilot study using a novel method to monitor insect populations as a proxy for the services they provide. The approach outlined includes details of a mobile app. developed by the project and as part of its legacy, which makes the survey approach accessible to citizen scientists and beneficial to conservation efforts nationwide.
- The framework presented here is a collaborative effort involving key stakeholders, an advancement towards best practice, evidence-led, a collection of guidance and case studies, and a foundation to build on. It is not fully comprehensive, not designed to meet every conceivable need, and is not the only solution to the challenge. The project team welcome constructive feedback. Readers are encouraged to test, adopt and develop the approaches offered, and to form networks to share experience and learning and to further develop best practice in monitoring outcomes of landscape-scale conservation.


Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

# Chapter 1: Introduction

Biodiversity and the resilience of ecosystems are declining at unprecedented rates. In response, conservationists have shifted from protecting individual species and sites to restoring the interactions of species, habitats and natural processes within a landscape context. However, the absence of best practice guidelines or established approaches for capturing data at the landscape-scale has hindered progress towards answering key questions posed by the government's environment white paper 'Making space for Nature'[1]. This paper catalysed the adoption of landscape-scale conservation approaches by government bodies and charitable organisations. Recognising the need to develop expertise and best practice approaches for biological monitoring at landscape-scales, Kent Wildlife Trust in consultation with others, developed the Nature's Sure Connected project. This landscape-scale monitoring framework is the primary output of the project and sets out practical guidance for answering a prioritised set of key questions about the outcomes of landscape scale conservation.

Image © Guy Edwardes 2020VISION

# Landscape-scale conservation

Species, habitats and ecosystems with limited ranges are vulnerable to disturbances and perturbations, with knock-on effects on the functions and services they provide. Landscape-scale conservation is a shift in focus from protecting individual species and sites, to restoring the interactions of species, habitats and natural processes at a broad landscape, or even larger regional, scale.

Landscape-scale conservation is the combined contribution of multiple actions, on multiple sites, by multiple stakeholders, to the resilience of ecological networks.

# The Lawton principles

Making Space for Nature, now widely known as the Lawton report, had immediate policy impact, shaping both the Natural Environment White Paper and the Biodiversity 2020 strategy. The Lawton report has stood the test of time, and the main conclusions are supported by peer-reviewed research. Consequently, the report continues to inform current policy, such as the Environment Bill, 25 Year Environment Plan and emerging thinking around Local Nature Recovery Strategies. Landscape-scale conservation is guided by the Lawton principles. The essence of what the conservation community aims to deliver is best summarised in four words by Lawton: *more*, *bigger*, *better* and *joined*. There are five key approaches which encompass the way in which these are delivered.

1. **Improve the quality of current sites through improved habitat management.**
2. **Increase the coverage of existing sites.**
3. **Enhance connections between sites, either through physical corridors, or through 'stepping stones'.**
4. **Create new sites.**
5. **Reduce pressure on wildlife through improved management of buffer areas and the wider environment.**

# The challenge

*Monitoring is an intermittent (regular or irregular) series of observations in time, carried out to show the extent of compliance with a formulated standard or degree of deviation from an expected norm.*[2]

Monitoring the outcomes of landscape-scale conservation presents significant challenges to the individuals and organisations involved in its delivery. The outcomes of landscape-scale conservation are the cumulative result of:

- multiple actions,
- on and across multiple sites,
- by multiple individuals and organisations,
- at large scales.

This results in a complex matrix of conservation interventions and policies in space and time. Desired outcomes are many and varied, from improving the fate of individual species and species assemblages, improving habitat quality, extent and

[1] Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., & Wynne, G.R. (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.
[2] Common Standards Monitoring: Introduction to the Guidance Manual (2004) Joint Nature Conservation Committee. https://hub.jncc.gov.uk/assets/f6fef832-93f0-4733-bf1d-535d28e5007e



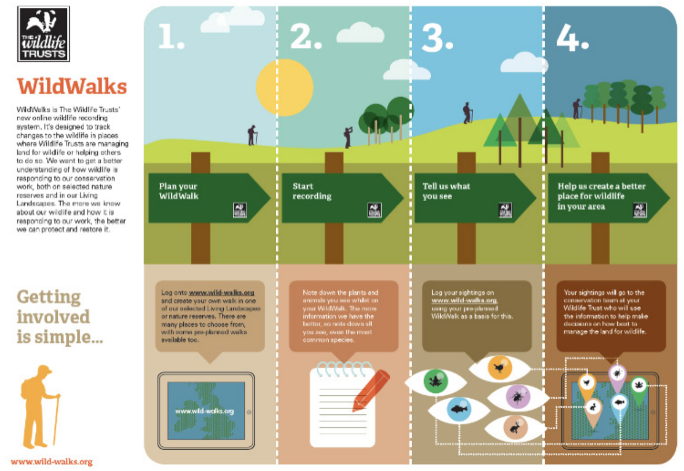


composition, to enhancing connectivity, ecosystem services, natural capital and natural processes. Site managers typically have the authority, responsibility and remit for monitoring on their own sites, but who has the responsibility and remit to monitor cumulative outcomes across sites and landscape areas comprising multiple ownership and management responsibility? What suitable data is available, and what new data is needed? What established methods and scales of data collection are suitable? Are new methods needed? These are some of the issues Nature's Sure Connected sought to tackle.

The purpose of monitoring always needs to be explicit. Four broad themes can be identified.

| | |
|---|---|
| **Hypothesis testing** | Is a management intervention having the desired effect (or not)? |
| **Effect size determination** | How well is a management intervention working? Can we quantify the effect of the intervention? |
| **Experimentation** | Does one intervention result in better outcomes than another? |
| **Adaptive management** | Can we use data to inform better management decisions as part of a dynamic strategy? |

Here, the focus is predominantly on hypothesis testing. Is landscape-scale conservation having the desired effect at landscape-scales?





# Rationale

Monitoring of site-scale outcomes is well-established and best practice such as Common Standards Monitoring, Breeding Bird Survey and the UK Butterfly Monitoring Scheme are available and widely adopted. Landscape-scale monitoring is in its infancy by comparison. The absence of common protocols and standards of approach for monitoring landscape-scale outcomes reflects both the infancy of the landscape-scale approach and the scale and complexity of the challenge. In recent years new systems have been developed, such as WildWalks, WildSurveys[3], and iRecord[4]. WildSurveys in particular was designed to provide a common framework within The Wildlife Trusts for the systematic recording of the temporal trends and responses of wildlife to habitat creation, restoration and management within Living Landscape schemes and on Wildlife Trust reserves. While there are many robust and valuable principles behind WildWalks and WildSurveys, they have not been widely adopted by The Wildlife Trusts, the reasons for which are discussed in Chapter 2.

The Landscape Partnership is a partnership between the four largest land-owning non-governmental organisations in the UK (The Wildlife Trusts, National Trust, Royal Society for the Protection of Birds and The Woodland Trust) which have committed to work together at a landscape-scale. This partnership held a workshop entitled 'Measuring the Impact of Our Landscape-Scale Work', which sought the views of 30 practitioners working in this field. Participants called for the development of a common framework for monitoring landscape-scale change and delivery, as the highest priority for their work.

Nature's Sure Connected sought to build on established thinking and progress the development of a common framework for monitoring the outcomes of landscape-scale conservation.

[3] A Users' Guide to WildSurveys online (2015) The Wildlife Trusts
[4] https://www.brc.ac.uk/irecord/

# Scope

Nature's Sure Connected (herein referred to as the project) aimed to enable Kent Wildlife Trust to make an organisational shift towards evidencing landscape-scale outcomes, by developing a landscape-scale monitoring framework and embedding it into our delivery. It also aimed to progress development of, and agreement on, best practice in landscape-scale monitoring among the wider conservation community. By consulting key stakeholders we aimed to ensure that this framework was developed by the people who need it, and suited the needs of other conservation organisations as well as our own. The project was run by Kent Wildlife Trust staff, volunteers, and with partner organisations. The project consultation reached over 200 practitioners from over 100 organisations within the UK conservation sector, and their contributions shaped the development of the project from the outset.

It was recognised that the project could not address every conceivable question that could be posed about the outcomes of landscape-scale conservation. Neither could it explore every approach to answering a given question. It therefore sought to prioritise key themes based on input and feedback from stakeholders, and to use the outcome of an audit and gap analysis of existing practice together with the needs of Kent Wildlife Trust and other organisations, to inform the development of the framework and the approaches herein.

The framework developed by the project draws on the contribution of multiple stakeholders. It contributes to the development of best practice and towards agreement on approaches. We hope it will be used and evolved by others to advance best practice and effective methods for the mutual benefit of the conservation community. We recognise however that it is not fully comprehensive, not designed to meet every need, or the only right answer to the challenge, and we welcome constructive feedback.

| What it is | What it isn't |
|---|---|
| A collaborative effort,<br>An advancement of thinking,<br>Evidence-based approaches,<br>Case studies,<br>A foundation to build on,<br>A suite of guidance and suggested best practice. | Fully comprehensive,<br>Designed to meet every need<br>The only answer. |



# Chapter 2: Project Approach

**The project sought to undertake a review of landscape-scale monitoring practices, and a gap analysis of current monitoring approaches. Stakeholders were consulted, including those working with the Wildlife Trusts, other conservation organisations, county species recording groups, land and resource managers, and academics, to gather expertise and information on the needs of the conservation community from landscape-scale monitoring. This informed the development and testing of a monitoring framework and practical approaches to landscape-scale monitoring. Partnership agreements were developed where appropriate, and volunteers were recruited and developed to aid the testing of the approaches. An overview of the project approach is detailed in Table 2.1.**

Image © Guy Edwardes 2020VISION

# Guiding principles

**The following principles were defined to guide the development of the project:**

- Stakeholder consultation from the outset was vital.
- Key questions must be defined and linked to specific themes and objectives of conservation actions at landscape-scales.
- Hypotheses must be testable.
- The distinction between physical, theoretical, and functional connectivity must be recognised.
- A robust, scientific framework and monitoring approach must be determined before the mechanism with which to deliver it is chosen.
- The approach developed must be flexible enough to meet the varied requirements of monitoring themes.
- Audit and gap analysis of existing practice should be conducted iteratively, not just at the outset.
- Stakeholders must be consulted before the approach is finalised.
- Developing partnerships is key to successful, sustainable outcomes.
- Timely review and revision is critical.
- Dissemination of project outputs should be planned at the outset and delivered on completion of the project.





# Pilot landscape areas

Based around four defined pilot landscape areas, at various spatial scales in Kent detailed in Figure 2.1, the project sought to develop suitable approaches to monitoring key themes prioritised by stakeholders. Landscapes of different scales were chosen to test the approaches developed as appropriate.

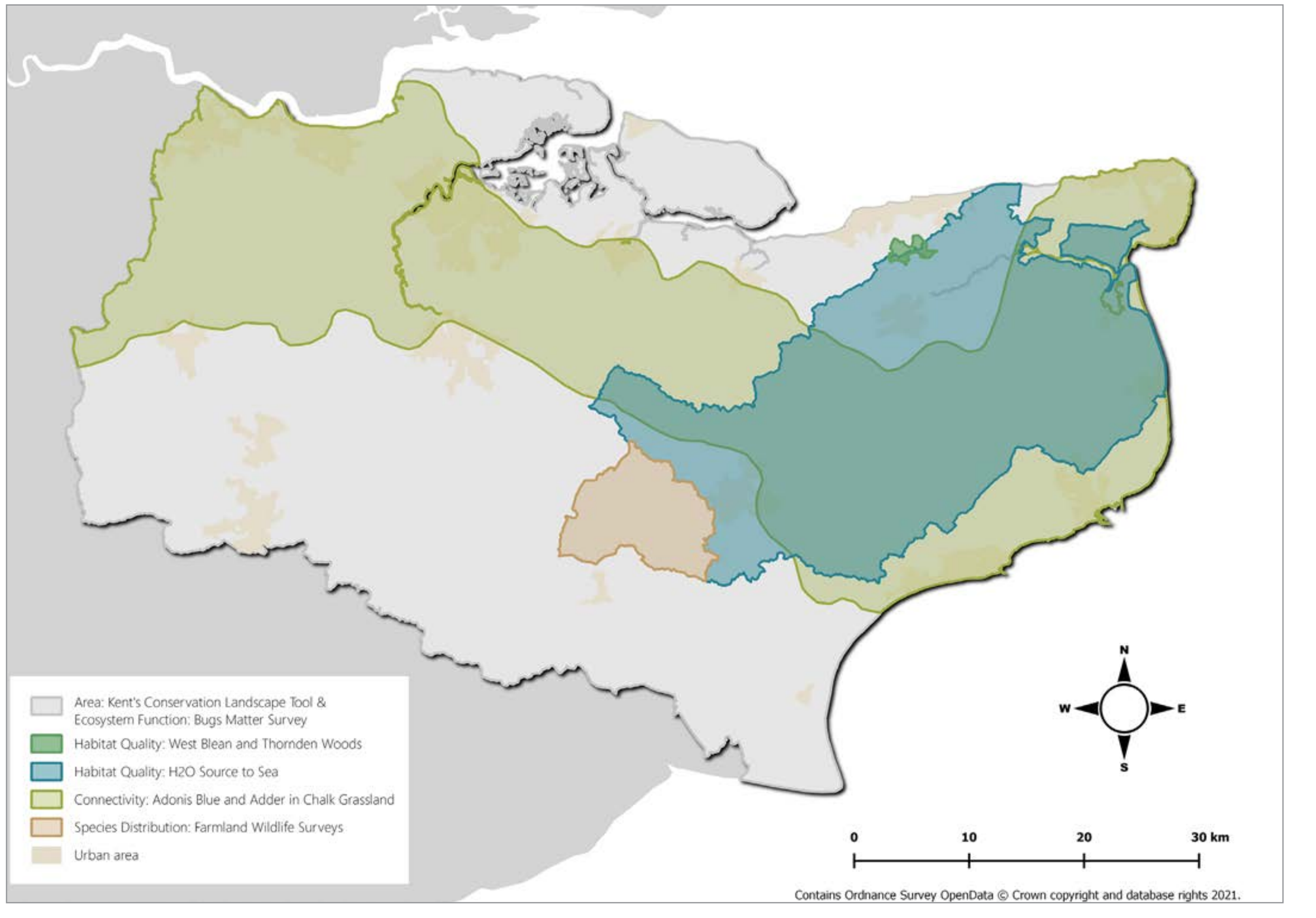



*Figure 2.1* **Pilot landscape areas of different scales in Kent, chosen to test the approaches developed by the project**

Project Approach
Guiding principles | Pilot landscape areas | Defining landscape-scale questions | Audit & analysis | Stakeholder consultation | Partnerships | Further development

*Table 2.1* **Detail of the approach taken to developing a landscape-scale monitoring framework, and overview of project outcomes and outputs**

| Project phase | Approach | Outcomes & *outputs* | |
|---|---|---|---|
| **Project governance** | • Technical advisory group – external.<br>• Steering group - internal. | • Project informed and guided by relevant expertise. | |
| **Defining landscape-scale questions** | • Key themes and questions identified.<br>• Themes and questions proposed to stakeholders. | • A question-led approach from the outset. | |
| **Stakeholder consultation** | • Online questionnaire. | • Established the landscape-scale action and landscape-scale monitoring that organisations deliver. | • Established the lack of consistency in the knowledge, resources and capacity to evidence landscape-scale outcomes. |
| | • Workshops. | • Established that we had posed the right questions.<br>• *A prioritised list of key questions.*<br>• *Criteria for selecting landscape-scale indicators.* | • Identified opportunities and challenges of a common framework.<br>• Established key principles of landscape-scale monitoring programs using case studies. |
| **Audit and analysis** | • Stakeholder consultation: audit of landscape-scale monitoring practice.<br>• Desk-top research: analysis of existing landscape-scale monitoring approaches.<br>• At key stages in framework and practical approach development. | • A list of current approaches established.<br>• The need for new approaches established. | • The needs from new approaches established.<br>• Approaches developed by the project informed by relevant information. |
| **Framework development – general approach** | • Desktop exercise consolidating and synthesising the information gathered through consultation, audit and analysis, to create a landscape-scale monitoring framework. | • *A landscape-scale monitoring framework.*<br>• *Guiding principles for defining landscape parameters.*<br>• *Ordered list of attributes of monitoring programmes.*<br>• *Defined themes to be addressed.* | • *A prioritised list of key landscape-scale questions.*<br>• *Hypothesis testing.*<br>• *Criteria for selecting landscape-scale indicators.* |
| **Framework development – practical, question-led approaches**<br>*Using the key questions prioritised by the project stakeholders, the project researched, tested and develop the following approaches, informed by the input provided by stakeholders through the consultation.* | | | |
| Chapter 4: **MORE**<br>**How much land is managed for wildlife?** | a) Review Kent Wildlife Trust's approach.<br>b) Research and review other approaches.<br>c) Develop and refine an approach to take forward.<br>d) Develop online recording and reporting tool.<br>e) Testing, including collaborative use by stakeholder organisations in Kent. | • Aspirational attributes, challenges and opportunities of an 'area managed tool' specified by project stakeholders.<br>• Comparative analysis of approaches to quantifying the area of land managed for wildlife at landscape-scale. | • *Specification and design blueprint for an 'area managed tool.'*<br>• *Case study: Monitoring the area of land managed for wildlife in Kent using the Kent's Conservation Landscape Tool.* |
| Chapter 5: **BETTER**<br>**What is the quality of habitats at landscape-scale and is it improving?** | a) Review and audit approaches<br>b) Establish approach best suited to landscape-scale conservation<br>c) Desktop research<br>d) Test practical approach to remote sensing using UAV technology:<br>a. Procurement<br>b. Training<br>c. Trial data collection<br>d. Trial analysis | • *Comparative assessment of existing approaches to habitat quality monitoring using floristic and vegetative attributes at landscape-scale.*<br>• *Comparative assessment of the questions remote sensing can answer and appropriate sensors.*<br>• *Comparative assessment of equipment options.* | • *Comparative assessment of software options.*<br>• *Comparative assessment of training options.*<br>• *Comparative assessment of insurance options.*<br>• *Case study – West Blean and Thornden Woods, remote sensing assessment of habitat quality.* |
| Chapter 6: **JOINED**<br>**Is there evidence of connectivity for species at landscape-scale, and has this changed in response to landscape-scale conservation?**<br>a) Establish connectivity indicators.<br>b) Modelling theoretical habitat connectivity.<br>c) Field survey to detect functional connectivity and validate modelling. | **Connectivity indicators**<br>a) Consolidate workshop feedback to create list of criteria for selecting indicators of landscape connectivity.<br>b) Define pilot landscape areas and choose suitable indicator species.<br>**Theoretical connectivity – modelling**<br>a) Review and audit modelling approaches.<br>b) Model connectivity for chosen indicator species using an appropriate modelling tool.<br>**Functional connectivity – field survey**<br>a) Develop survey design and approach.<br>b) Recruit and train volunteers.<br>c) Conduct field survey.<br>d) Data analysis and reporting.<br>e) Review and refine approach. | • *Comparative analysis of modelling approaches, and application to assessing functional connectivity.*<br>• *Comparative analysis of field survey methods for connectivity.*<br>• *Case study and practical guidance in using Circuitscape to quantify changes in connectivity.* | • *A practical field survey method to monitor functional connectivity for species.*<br>• *Case study: practical application of a field survey method to detect functional connectivity for species in the North Downs, Kent.* |
| Chapter 7: **BIODIVERSITY**<br>**What are the trends in species populations at landscape-scales?** | a) Review and audit approaches.<br>b) Develop and test a practical approach. | • *Comparative assessment of field survey methods.*<br>• *Field survey approach.* | • *A review of recent advances in the application of national datasets to the assessment of landscape-scale trends.*<br>• *Case study: Monitoring farmland bird distribution in the Upper Beult farmer cluster.* |
| Chapter 8: **ECOSYSTEM FUNCTION**<br>**Can we use large numbers of untrained volunteers to collect useful data about insect populations?** | a) Audit ecosystem functions and services.<br>b) Review and audit approaches.<br>c) Develop and test a practical survey approach.<br>d) Review and refine approach. | • *'Bugs Matter' insect abundance survey approach.*<br>• *Case study: Bugs Matter – Citizen scientist-led monitoring of ecosystem function at landscape-scale demonstrates temporal difference in invertebrate abundance in Kent and South-East England.* | • *Design specification for a mobile app.*<br>• *Project Legacy - The Bugs Matter mobile app.* |

# Defining landscape-scale questions

Recognising that effective evaluation of outcomes, and collection of the right data to do so, relies on clearly articulating the question at the outset, key themes and questions were defined based around landscape-scale conservation principles. While individual organisations and projects are likely to develop their own project-specific and landscape-specific questions, there are general themes and questions about landscape-scale conservation outcomes that a common framework might seek to address. These questions were used to inform the format and basis of the stakeholder consultation.

| Landscape-scale conservation principle | Landscape-scale conservation questions |
|---|---|
| **MORE** | Are there more sites for nature? |
| **BIGGER** | Is the area of habitat/land managed for wildlife increasing?<br>Is the area of key habitat types increasing? |
| **BETTER** | Is habitat quality improving?<br>Is management practice improving? |
| **JOINED** | Is the landscape physically more connected?<br>Is the landscape theoretically more connected?<br>Is the landscape functionally more connected? |
| **BIODIVERSITY** | Are there more species in the landscape?<br>Are population sizes increasing?<br>Are species distributions increasing? |

View across the Darent Valley to Polhill, West Kent. (© C.Blackburn)





# Audit and analysis

Audit and analysis of existing landscape-scale monitoring practice were conducted at three stages in the project:

1. **Desk-based audit**: an initial audit of existing broad frameworks for landscape-scale monitoring.
2. **Stakeholder consultation:** gathering knowledge, expertise, and experience of landscape-scale monitoring to feed into project development.
3. **Development and testing**: in developing practical monitoring approaches around each key theme prioritised by project stakeholders, existing approaches and methods were audited and analysed. Outcomes of these approaches are detailed in the relevant chapters.

## Desk-based audit

Key considerations that are important in any ecological monitoring framework provided a basis for assessing the suitability of existing methods. These were informed by Pocock et al (2015)[1].

- Key questions must be defined and/or clear monitoring objectives articulated.
- Indicator, metric, species selection, site selection, and survey method must be defined before an appropriate mechanism is chosen.
- A robust, scientific approach must be determined, before the mechanism with which to deliver it is chosen.
- The mechanism chosen must be flexible enough to meet the requirements of the approach.
- Stakeholders must be consulted before approach is finalised.
- It is vital to articulate the question you seek to answer, before assessing and choosing the approach by which you intend to answer it.

An adapted, ordered list of the most essential to most aspirational attributes of monitoring programmes is signposted as part of the landscape monitoring framework (Chapter 3, OP3.3). These attributes informed the analyses of the suitability of existing landscape monitoring practices for answering the key landscape-scale conservation questions identified above.

## Subjective, comparative analysis of existing landscape monitoring approaches

A simple three-level scoring approach was used to assess the suitability of a variety of existing landscape-scale monitoring approaches for addressing requirements of a landscape-scale monitoring programme. While subjective, it usefully provided a simple demonstration of the strengths and weakness of different approaches and identified that elements of all could usefully inform this framework. It also identified some gaps that a common approach needed to address. This analysis is detailed in Table 2.2.

## 'SWOT' analysis of existing landscape monitoring approaches

A more detailed SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis of three 'off-the-peg' monitoring frameworks was conducted and is detailed in Table 2.3.

[1] *Pocock, M. J. O., Newson, S. E., Henderson, I. G., Peyton, J., Sutherland, W. J., Noble, D. G., … Roy, D. B. (2015). Developing and enhancing biodiversity monitoring programmes: A collaborative assessment of priorities. Journal of Applied Ecology, 52, 686–695.* https://doi.org/10.1111/1365-2664.12423

*Table 2.2* **Subjective, comparative analysis of existing landscape monitoring approaches**

| Attribute assessed | WildWalks | WildSurveys | iRecord | Connectivity Modelling | Remote Sensing | Field Survey |
|---|---|---|---|---|---|---|
| Analytical power | 1 | 2 | 1 | 3 | 3 | 3 |
| Appropriate analytical and statistical approaches available | 1 | 3 | 3 | 3 | 3 | 3 |
| Appropriate, scientific, sampling design | 2 | 3 | 1 | 1 | 1 | 1 |
| Best practice shared between organisations and schemes | 2 | 2 | 3 | 3 | 3 | 3 |
| BETTER quantified | 1 | 3 | 1 | 1 | 3 | 3 |
| Bigger quantified | 1 | 1 | 1 | 1 | 3 | 1 |
| Biodiversity trends quantified | 2 | 3 | 3 | 1 | 2 | 3 |
| Compatibility with other systems and frameworks | 2 | 1 | 3 | 3 | 3 | 3 |
| Cost | 3 | 3 | 3 | 3 | 1 | 2 |
| Data is reliable and validated | 2 | 2 | 3 | 3 | 3 | 3 |
| Discriminatory power | 1 | 3 | 2 | 3 | 3 | 3 |
| Efficient data entry, storage and processing systems | 3 | 3 | 3 | 3 | 3 | 3 |
| Electronic data capture | 3 | 3 | 3 | 3 | 3 | 2 |
| Existing app./interface | 3 | 3 | 3 | 1 | 1 | 2 |
| Flexibility | 1 | 2 | 1 | 3 | 3 | 3 |
| Focus on important species, locations, habitats etc | 3 | 3 | 3 | 3 | 3 | 3 |
| Indicator species defined | 1 | 1 | 1 | 1 | 1 | 1 |
| Indicator taxa defined | 1 | 3 | 1 | 1 | 1 | 1 |
| JOINED quantified | 1 | 2 | 1 | 3 | 2 | 1 |
| Landscape-scale coverage | 2 | 2 | 2 | 3 | 3 | 2 |
| National, regional, or local coordination | 3 | 3 | 1 | 1 | 1 | 3 |
| Population distribution quantified | 2 | 3 | 3 | 1 | 2 | 3 |
| Population size quantified | 1 | 2 | 1 | 1 | 1 | 3 |
| Results and findings fed back to participants | 3 | 3 | 2 | 2 | 2 | 2 |
| Results disseminated widely | 1 | 1 | 1 | 1 | 1 | 3 |
| Simple reporting of widespread and common species/attributes available to all | 1 | 1 | 3 | 1 | 1 | 3 |
| Species recorded | 3 | 3 | 3 | 1 | 1 | 3 |
| Suitable and accessible identification resources | 3 | 3 | 3 | 3 | 3 | 3 |
| Suitable, accurate, efficient sampling methods | 1 | 3 | 2 | 3 | 3 | 3 |
| Supplementary data gathered (i.e. habitat soil, weather) | 1 | 2 | 1 | 1 | 1 | 3 |
| Survey design principles inherent in approach | 2 | 3 | 1 | 1 | 1 | 3 |
| Volunteer-friendly | 3 | 2 | 3 | 1 | 1 | 3 |
| **Total score** | **60** | **77** | **66** | **63** | **66** | **81** |





*Table 2.3* **'SWOT' analysis of existing landscape monitoring approaches**

| Approach | Strengths | Weaknesses | Opportunities | Threats | Summary |
|---|---|---|---|---|---|
| **WildWalks**<br>A broad survey of species (many or a few targeted) widely throughout landscape with limited control over how robust, reliable and useful the data will be. | • Species recorded.<br>• Free and 'off-the-peg'.<br>• Online interface.<br>• Landscape-scale.<br>• Volunteer-friendly.<br>• Potential for large-scale engagement. | • Specific questions not defined.<br>• Poor compatibility with other systems.<br>• Not able to answer all key questions.<br>• Lacks guidance on landscape indicator species or metrics.<br>• Lacks framework for detecting landscape-scale outcomes.<br>• Habitat quality not assessed.<br>• Poor analytical power.<br>• Inflexible – only supports walk-based sampling. | • Possible to adopt approach withing new landscape monitoring frameworks. | • Poor uptake by volunteers.<br>• Future support and funding unclear, withdrawn at time of writing. | A cheap and easy way to collect lots of the least useful data. |
| **WildSurveys**<br>A Wildlife Trust framework for systematic recording of the responses of wildlife to habitat creation, restoration and management in landscape schemes and on Wildlife Trust reserves. Targeted survey of key habitat/taxa/species, with good ability to answer some key questions. | • Species recorded.<br>• Free & 'off-the peg'.<br>• Online interface.<br>• Landscape-scale.<br>• Survey design principles.<br>• Questions defined.<br>• Guidance on habitat specific taxa. | • Focused on outcomes on sites within landscapes rather cumulative outcomes across landscapes.<br>• Interface less volunteer friendly.<br>• Poor compatibility with existing in-house systems.<br>• Duplicates or isolates work- and data- flows from other systems (GIS, databases, analysis).<br>• Not able to answer all key questions.<br>• Lacks guidance on target species and metrics for landscape-scale outcomes.<br>• Inflexible and constraining compared to other systems. | • Nature's Sure Connected could feed into further development to better suit needs. | • Has not been widely adopted due to limitations.<br>• Future support and funding unclear, withdrawn at time of writing. | A theoretically excellent, general 'off-the-peg' approach to answer a narrow range of questions but lacks ability to answer all of the key questions, isolates workflows from existing more powerful and flexible systems. Would need further informing by robust design and scientific principles not inherent in the format to provide a comprehensive solution. |
| **iRecord**<br>A web-based species recording database that makes it easier for wildlife sightings to be collated, checked by experts and made available to support research and decision-making at local and national levels. | • Off the peg web interface.<br>• Free, 'off-the-peg'.<br>• Excellent and effective collation of species records.<br>• Developed by Biological Records Centre.<br>• Landscape coverage.<br>• Public profile.<br>• Volunteer-friendly.<br>• Compatible with current systems. | • No guidance on survey design.<br>• No guidance on target species.<br>• No guidance on target areas.<br>• No analytical capability.<br>• Lacks flexibility to incorporate survey structure.<br>• No metrics for habitat quality, connectivity, biodiversity trends.<br>• A database, rather than a framework solution. | • Potential use as primary database solution within landscape monitoring frameworks. | • None identified. | The best free and flexible tool for the collection of species data from the landscape, but not designed for the purpose of monitoring landscape-scale outcomes, lacking the framework and flexibility required as an off-the-peg solution. |

# 1. Stakeholder consultation

A stakeholder consultation was conducted both by online questionnaire and three workshops. An initial stakeholder mapping exercise identified 331 stakeholders, across local (Kent) and national (UK) scales. Stakeholders were invited to join a mailing list, which attracted 288 subscribers from across the conservation sector. In total 223 people from 103 conservation organisations took part in the consultation.

The consultation was designed to:

a) Establish whether the right key themes and questions about landscape-scale conservation outcomes had been defined by the project.

b) Collaboratively create a prioritised list of the themes and questions considered most important to answer by the stakeholder community.

c) Create a list of criteria for selecting landscape-scale indicators.

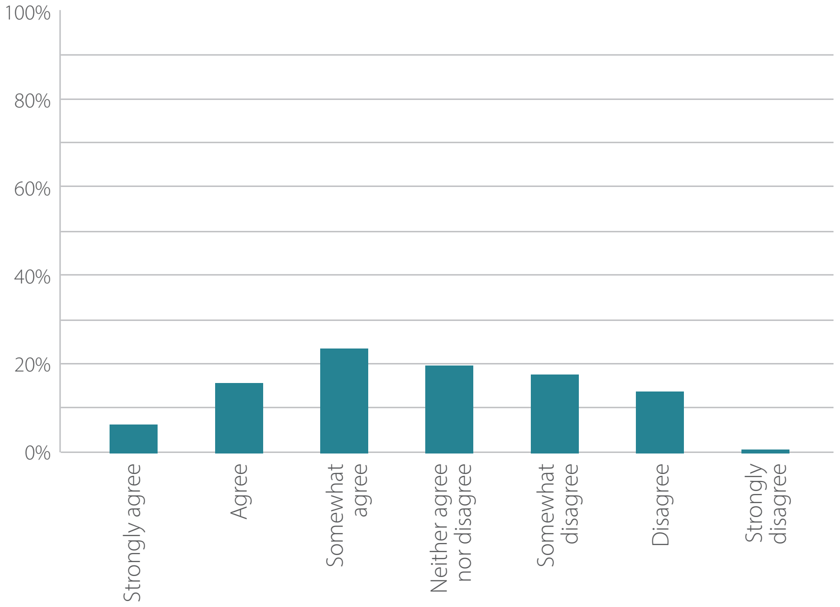
d) Identify the opportunities and challenges of creating and using a common, landscape-scale monitoring framework.

e) Establish the principles of specific landscape-scale monitoring programs using case studies.

## Stakeholder consultation: online questionnaire

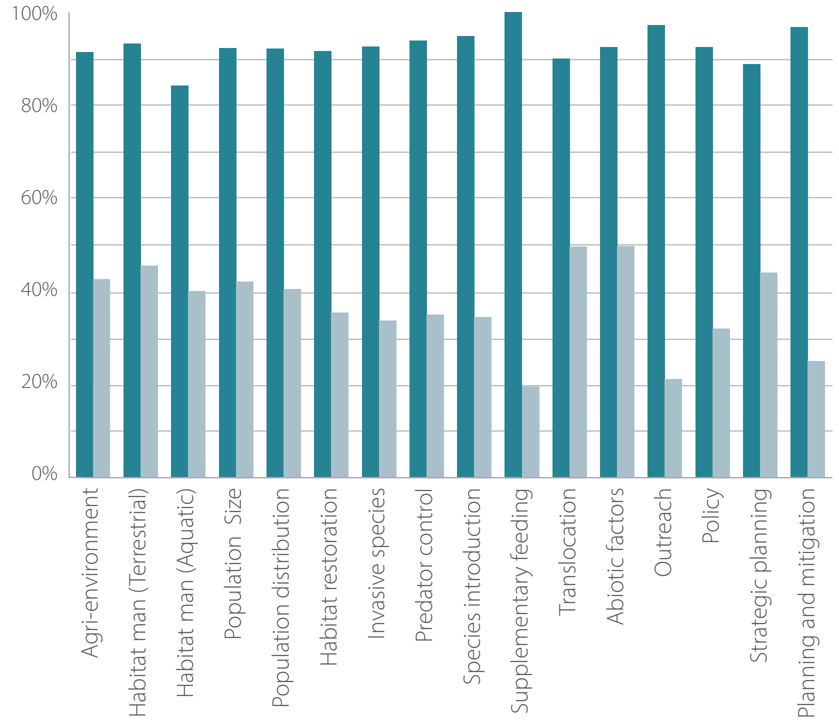
The online questionnaire consultation received 106 responses.

1) We asked stakeholders whether their organisation was currently able to effectively evidence the outcomes of its landscape-scale conservation actions.




Approximately half of respondents told us they could evidence outcomes of landscape-scale conservation action. Their experience was invaluable in informing development of this framework.

2) We asked stakeholders what types of conservation action they **deliver**, and which of these types of work they monitor at the landscape scale:

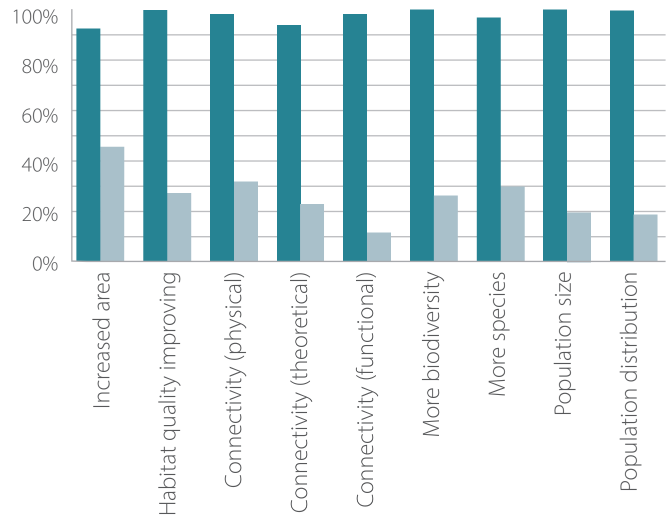



Many stakeholders do a variety of work across landscapes, however frequently only half (or fewer) of respondents said they monitor that work.



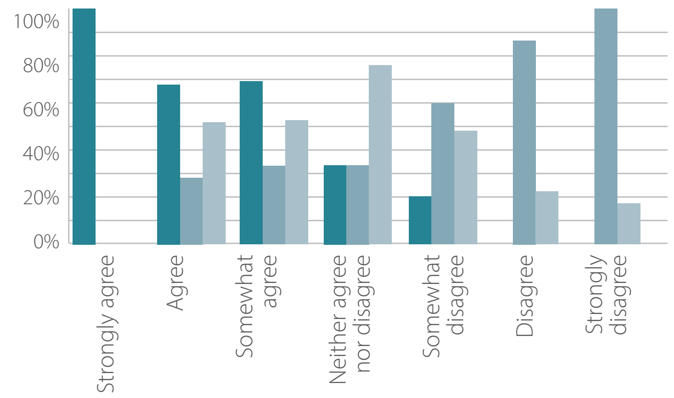


3) We presented a number of key landscape-scale conservation questions, and asked if stakeholders thought each was **important**, and which of them they are actually answering. We also asked if there were other key questions they considered important to answer.




Most respondents agreed the questions we proposed were important, but very few were answering them through monitoring. Additional questions posed by respondents typically related to outcomes of specific management techniques, rather than landscape-scale outcomes, and did not relate to the aims and scope of the project.

4) We then asked if stakeholders felt their organisation currently had the **understanding**, resources, and tools and guidance to evidence the outcomes of landscape scale conservation action:




Many stakeholders in the community know how to do it, some have the tools and guidance to do it, but few have the resources to do it. This told us that there were gaps in the availability of tools and guidance, and that approaches need to be efficient and cost effective.

## Stakeholder consultation: workshops

A series of workshops were convened to facilitate a collaborative consultation approach. All stakeholders were invited to attend one of three workshops in either Kent, or London, to provide accessibility to national organisations. In total 60 practitioners in conservation delivery, evidence and research contributed through their attendance at one of these workshops. The overarching aim of the workshops was to establish the principles of a common landscape-scale monitoring framework. A description of the breakout activities participants were asked to contribute to, the aims and a summary of the outcomes of each activity are detailed in Table 2.4 below. The outcomes are discussed thereafter.

*Table 2.3* **Summary of the breakout sessions workshop participants contributed to, to establish the principles of a common landscape-scale monitoring framework**

| Activity number | Description | Aim | Summary of outcomes |
|---|---|---|---|
| 1 | What are our conservation objectives?<br>Which of these objectives are shared across the conservation community?<br>What are the actions we take to deliver these objectives?<br>Which of these actions are shared across the conservation community? | To establish what actions we take, and what outcomes aim to achieve. | Acknowledgement that our shared objectives are a cumulative result, and that we need a common framework to evidence them. |
| 2 | Are these the right questions and are any missing?<br>Are they future-proof?<br>What three themes/questions do you think are most important for the framework to address? | To agree on the most important themes and questions the framework should address. | A prioritised list of key themes and questions the project should address, important to all stakeholders, that if answered will demonstrate the success of landscape-scale conservation. |
| 3 | What would be the opportunities and challenges of a common framework?<br>How could we address them?<br>What does a successful monitoring programme look like? | To anticipate the benefits and challenges of developing a common approach to evidencing landscape scale conservation | Guidance to steer the direction and creation of a landscape monitoring framework. |
| 4 | How should we decide what to monitor?<br>What indicators could work at a landscape-scale and why? | To establish the most important criteria for selecting landscape scale indicators. | A list of criteria for selecting landscape scale indictors, developed collaboratively. |
| 5 | Devise a simple monitoring programme to answer one of the key questions prioritised in 3.<br>Include what, how, who, where, opportunities for partnership working, can include recommendations larger than scope of this project. | To establish practical plans for answering the prioritised questions. | Eight outline plans to address the key themes and questions identified to inform the development of the approaches taken forward by the project. |





# Key workshop outcomes

- **Acknowledgement that our shared objectives are a cumulative result, and that we need a common framework to evidence them.**
  Participants shared a desire to see the natural environment in a better state, more resilient, better connected and to reverse negative trends; that the natural environment should be better protected, understood and managed, and that the drivers of change should be better understood; better and more open data collection and sharing is needed; better relationships between conservation organisations and landowners are needed; sustainable use of natural resources, both terrestrial and marine is required.

- **A prioritised list of key questions the project should address, important to all stakeholders, that if answered will demonstrate the success of landscape-scale conservation.**
  There was widespread consensus that the right questions had been posed, all were important, and it was stressed that they should be Specific, Measurable, technically Achievable, Relevant, and Temporally-related. Additional questions suggested tended to focus on specific outcomes of individual management actions, rather than cumulative outcomes across landscapes, or were not explicit in addressing landscape-scale outcomes. It was recognised that limitations to data collection are not always resources, but the knowledge and expertise to target efforts in the most effective ways. Answering the easy versus the hard questions was debated, and the consensus was that the easy questions were less of a priority for the project to address. Priority was given to those that will impact what we actually do. Future-proofing was also discussed, flexibility must be written in, indicators may change with climate change, and species may go extinct. Common species may become rare; today's escapes may become tomorrow's naturalised species. We should anticipate that key indicators in the present may not be suitable, or indeed present in the future, and that new ones may be required.

- **Increased awareness of the opportunities and challenges of a common monitoring framework, and ideas to address them.**
  A wealth of opportunities of a common framework were identified:
  - A common framework and consistent, coordinated approaches could provide more effective monitoring, generate more lobbying power, and create greater profile and impact of findings, through unified, consistent messaging and approaches.
  - The opportunity to link this framework to government frameworks such as the 25-year Environment Plan which includes three priorities for surveillance and monitoring: ecosystem services, informing local decision making & policy decision commitments (though lacks mechanisms for delivery), and the National Planning Policy Framework.
  - Efficiencies and economies of scale in the use of a common framework and sharing of limited resources.
  - A common framework, both in terms of principles and methods, could be applied across borders and devolved nations.
  - There is an existing community of experts, citizen scientists, and natural historians, and opportunities to share expertise and create best practice guidance and to maximise value of the existing biological recording network.
  - A plethora of existing recording and monitoring schemes provides opportunity for integration and data sharing.
  - Opportunity for improved data consistency, compatibility and sharing - including creation of data.
  - Advances in the quality, quantity and accessibility of earth observation/remote sensed data.
  - New ways of working, new technology and availability of technology.
  - Opportunity to create common data terminology that is user-friendly for a general audience.
  - Brexit could create a shakeup and may influence and improve monitoring schemes.
  - Opportunities to create new landscape partnerships and collaborations, and to jointly apply for funding.
  - Opportunities to develop accurate habitat mapping.
  - Opportunities to build on existing schemes and methodologies and apply them at a landscape-scale.
  - Opportunity to create a monitoring framework to evidence Nature Recovery Networks.
  - Kent Wildlife Trust to work with NASA to produce an 'earth rover'!
  - More partners and collaborators would provide a longer legacy.

- **A list of criteria for selecting landscape-scale indictors, developed collectively.**
  See Chapter 3.

- **Outline plans to address the key questions.**
  Used to inform the development of practical approaches within the framework (Chapters 4-8).

# Partnerships

Recognising a need for both Kent Wildlife Trust and other organisations to enhance their capacity to deliver landscape-scale monitoring, and the opportunities presented by working collaboratively across landscapes, the project sought to identify, develop, and highlight to stakeholders, partnership working agreements with organisations that supported the development of the approaches to answering the key themes prioritised by stakeholders.

Working in partnership delivers greater resilience to statutory funding changes, competing interests of and competition for volunteers, and access to expertise and shared resources for monitoring. Much of the data relied upon is collected by an aging voluntary biological recording community, an issue that is widely recognised among the conservation community. New volunteers must be inspired to take up recording, to strengthen and provide longer-term sustainability in the recording community, bolstering and supporting the volunteer asset that the conservation sector relies upon. Working in partnership provides a mechanism to collaborate strategically to develop joined-up approaches, prioritised for evidence needs across landscapes and between stakeholders.

The project developed partnership working agreements with Butterfly Conservation, Kent Reptile and Amphibian Group, Southern Water, Natural England and Conservation Evidence to support the evidencing of landscape-scale outcomes of landscape-scale conservation. These are detailed in Table 2.5.


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*Table 2.5* **Partnership agreements secured by the project to support the development of evidencing landscape-scale monitoring**

| Partner organisation | Landscape-scale monitoring theme | Purpose of agreement |
|---|---|---|
| *Butterfly Conservation Kent and South East London Branch*<br><br>*Kent Reptile and Amphibian Group* | **JOINED**<br>Is there evidence of connectivity for species at landscape-scale, and has this changed in response to landscape-scale conservation? Functional connectivity for species. | • To support the design and delivery a monitoring program to assess functional habitat connectivity using butterflies and reptiles as model indicator species to assess the state of nature at landscape-scales.<br>• To facilitate provision of expert advice on the selection of landscape indicator species and survey design.<br>• To facilitate new and existing volunteers to support the monitoring objectives of partner organisations.<br>• To promote avenues for project volunteers to get involved with partner organisations at the end of project to further the sustainability of butterfly and reptile monitoring for mutual benefit. |
| *Southern Water & Upper Beult Farmer Cluster* | **BIODIVERSITY**<br>What are the trends in species populations at landscape-scales? | • To work collaboratively to develop suitable approaches to evidencing landscape-scale outcomes in farmed landscapes using the *Farmer Cluster* initiative as a model. |
| *Natural England* | **BETTER**<br>What is the quality of habitats at landscape-scale? | • To develop fit-for-purpose targets for Sites of Special Scientific Interest (SSSIs) condition assessment in the context of wilding/rewilding, an increasingly prevalent and progressive approach to landscape-scale conservation. |
| *www.conservationevidence.com* | Evidence for the effectiveness of conservation actions, at all spatial scales. | • To provide recognition of Kent Wildlife Trust's accreditation as a *Conservation Evidence Champion*.<br>• To provide public demonstration of Kent Wildlife Trust's evidence-based practice.<br>• To improving the testing, monitoring and reporting of conservation interventions at all scales working to agreed standards.<br>• To promote the testing and publishing of the outcomes of interventions, and demonstrate leadership in conservation.<br>• Promoting the work of each other's organisations.<br><br>Legacy resulting from this agreement includes Kent Wildlife Trust taking a joint lead role in chairing the *Evidence in Conservation Practice Working Group*, a group of global conservation practitioner and funder organisations, and contributing to a number of initiatives to better integrate evidence use in conservation practice. |

# The need for further development

WildSurveys, a common Wildlife Trust framework for systematic recording of the responses of wildlife to habitat creation, restoration and management in landscape conservation schemes, was expected to offer a solution to landscape-scale monitoring for Wildlife Trusts. It is well designed by experts and contains much excellent guidance and scientific rationale, and of the existing landscape monitoring frameworks, the one most suited to the task. Additional guidance on how to select appropriate subsets of species for monitoring landscape-scale outcomes in different habitats or regions had been mooted but did not materialise. No guidance on indicator species selection to answer some of the key landscape-scale questions identified by the project was included, and the future of WildSurveys became uncertain. It is not currently funded or supported by the organisations that developed it and it seems highly unlikely that it will be supported in the future.

WildSurveys had a strong focus on Wildlife Trust-managed land and site-based monitoring, and didn't offer guidance on or functionality to monitor outcomes at a truly landscape-scale, i.e. throughout the entire landscape matrix. It had a focus on outcomes for particular sites within landscapes, rather than on the cumulative outcomes of multiple interventions throughout landscapes. It had a 'clunky' web-interface, rejected by many in favour of the greater flexibility, analytical power and compatibility and integration with other open-source platforms such as Recorder 6, QGIS and R. If other platforms are used within an organisation, using WildSurveys could duplicate data storage, processing and analysis flows across different systems and platforms. The inbuilt GIS functionality is far outperformed by open source and proprietary platforms now commonly used by conservation organisations. At a most basic level, it lacked the functionality to upload existing polygons of reserve/parcel boundaries, or to export shapefiles. It provided a framework to answer only some of the key questions we seek to answer, and not all of those identified thought the consultation conducted by this project. It lacked fully landscape-scale applicability. The availability of frequently emerging and updated open-source plugins for open-source platforms, far faster than WildSurveys could be updated, caused it to lag severely behind in functionality compared to other systems. These plugins extend the functionality of open-source platforms to carry out particular tasks more efficiently and effectively. For example, the Field Studies Council QGIS plugin[2] provides the ability to source biological records directly from Recorder 6 within the QGIS platform. WildSurveys was not widely adopted by The Wildlife Trusts.

Conservation outcomes are not confined to sites managed by Wildlife Trusts, or even to managed sites. Conservation action is not confined to these sites either, and is not focused only on the management of sites. It also includes advocacy, and the development and influence of policies that influence sites, counties and countries at all spatial scales, for example. The common goals of landscape-scale conservation are a result of a plethora of action far beyond site management, and fit-for-purpose monitoring must encompass this and detect the resulting cumulative outcomes, while accepting that causation is more difficult, and may be impossible in certain instances, to prove.

Guidance from Wild Surveys does inform monitoring practice. For example, the guidance around structuring data collection across *core, restoration, new* and *connecting* habitat as a way of measuring outcomes of landscape-scale conservation, has been adopted by Kent Wildlife Trust, to understand the outcomes of site focused management practices at landscape-scale.

Stakeholders throughout, and outside of the Wildlife Trust movement when consulted by the project, acknowledged that landscape-scale conservation outcomes are a cumulative result of multiple organisations working at a variety of scales within landscapes, and that we need a common framework to evidence our shared monitoring objectives. A prioritised list of key questions, important to all stakeholders, that if answered, will demonstrate the outcomes of landscape-scale conservation was established through this consultation. Existing monitoring frameworks do not provide sufficient guidance or approaches to answering all of these. The consultation generated an increased awareness of the opportunities and challenges of developing a common monitoring framework, and ideas to address them have been incorporated into the development of the framework outlined here. A common framework and consistent, coordinated approaches could provide more effective monitoring, generate more lobbying power, and a create greater profile for, and impact of findings, through unified, consistent messaging and approaches. A list of criteria for selecting landscape scale indictors, developed collectively, established a basis for addressing key questions around connectivity, and outline plans to address the key questions developed by stakeholders have been used to inform the development of practical approaches (Chapters 4-8).

Existing landscape-scale monitoring approaches and frameworks have valuable elements, however none offers a comprehensive solution to the needs of the stakeholder community. By consulting the community, those needs were identified, and key questions defined and prioritised, to ensure that monitoring can be developed to allow robust hypothesis testing in resource efficient ways. This learning informed the development of the monitoring framework presented here.

[2] https://www.fscbiodiversity.uk/blog/future-new-fsc-qgis-plugin-features



# Chapter 3: Framework Structure

**The project sought to develop and structure a landscape-scale monitoring framework around the key themes and questions prioritised by the conservation community. These broad, overarching and most fundamental principles of landscape-scale conservation were considered the priority for this project, and link directly to landscape-scale outcomes that are the cumulative result of the multitude of interventions undertaken by the wide variety of intervention, management, and policy actions taken by stakeholders in landscapes. While more specific, detailed and granular questions about the outcomes and effectiveness of specific interventions are important, addressing these was outside the remit and scope of this project.**

**This framework is based on a series of logical steps from defining the parameters of the landscape of interest to ensure that what can and cannot be determined is made explicit, clearly articulating the questions of interest, considering the essential attributes of the monitoring programme, and selecting appropriate indicators, metrics and identifying data needs. The framework structure signposts the relevant practical monitoring approaches developed by the project, and the specific project outputs linked to elements within the framework.**

Image © David Tipling 2020VISION

# A landscape-scale monitoring framework

**Signposting: Project outputs and guidance to inform monitoring approaches.**



| Logical steps | | | | | |
|---|---|---|---|---|---|
| **1. Define landscape-scale of study area.**<br><br>Define the scale and boundary of the focal landscape at the outset. This may be arbitrarily or functionally delineated, and this choice places constraints and caveats on the scope and limits of data interpretation. | **2. Define monitoring theme(s).**<br><br>Landscape-scale outcomes can be categorised into broad themes. To inform and direct monitoring approaches, it is useful to structure a monitoring framework around these themes, to ensure the aims, scope and objectives of monitoring are clearly defined, and to inform the articulation and rationale of monitoring objectives, questions or hypotheses.<br><br>*OP3.4* **Defining monitoring themes and rationale.** | **3. Articulate the monitoring objective, question or hypothesis.**<br><br>It is vital to decide on and define the questions we are trying to answer at the outset, before designing a monitoring plan or strategy. | **4. Consider the attributes required of the monitoring programme.**<br><br>Successful monitoring programmes incorporate a range of key attributes that can be ranked from most fundamental to most aspirational. | **5. Select indicators, metrics, methods, and establish data needs.**<br><br>The project developed guidance around a range of factors to facilitate the choice and use of suitable approaches. | **6. Identify practical monitoring approach.**<br><br>Approached developed by the project are detailed in the chapters indicated. |
| *OP3.2* **Guiding principles for defining landscape parameters.** | **MORE:**<br>The extent of land managed for conservation. | The monitoring objective, question or hypothesis will dictate:<br>• The type of data required.<br>• The amount of data required.<br>• The method of data collection.<br>• The power of the analysis.<br><br>*OP3.5* **Prioritised list of key landscape-scale questions.**<br>*OP3.6* **Articulating the question and hypothesis testing.** | *OP3.3* **Ordered list of attributes of monitoring programmes.** | • *OP4.1* **Specification and design blueprint for an area managed tool.** | Chapter 4 |
| | **BETTER:**<br>Improved quality of current sites by better habitat management. | | | • *OP5.2* **Comparative assessment of remote sensing sensors and the habitat quality attributes measured.**<br>• *OP5.3* **Comparative assessment of hardware and deployment solutions for UAV-based rote sensing.**<br>• *OP5.4* **Comparative assessment of software options for image processing.**<br>• *OP5.5* **Comparative assessment of UAV pilot training options.**<br>• *OP5.6* **Comparative assessment of UAV insurance options.**<br>• *OP5.7* **Case study – West Blean and Thornden Woods: digital surface modelling to assess structural attributes of habitat condition.** | Chapter 5 |
| | **JOINED:**<br>Improved habitat connectivity. | | | • *OP3.7* **Criteria for selecting landscape-scale indicators.**<br>• *OP6.1* **Comparative analysis of modelling approaches, and application to assessing functional connectivity.**<br>• *OP6.2* **Comparative assessment of the application of field survey approaches to detecting connectivity.**<br>• *OP6.3* **Case study: a practical approach to modelling and quantifying landscape connectivity for species using Circuitscape.**<br>• *OP6.4* **A practical field survey approach to detecting functional connectivity for species at landscape-scale.**<br>• *OP6.5* **Case study – testing a field survey approach to detect functional landscape connectivity using indicator species.** | Chapter 6 |
| | **BIODIVERSITY:**<br>Species trends and demography. | | | • *OP7.2* **A practical field survey approach to assessing species abundance using occupancy.** | Chapter 7 |
| | **ECOSYSTEM FUNCTION** | | | • *Table 8.1* **Overview of ecosystem services and functions.**<br>• *OP8.1* **Bugs Matter citizen science survey of insect abundance'** | Chapter 8 |


Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

# OP3.2 Guiding principles for defining landscape parameters

Defining the parameters of a study landscape is vital at the outset, to ensure that the scope of data collection, analysis and interpretation are explicit. In practice it is often likely to be difficult to achieve satisfactory functionally-defined (i.e. ecologically delineated) landscape boundaries within which to frame monitoring objectives due to the inherent connectivity of land (and sea) with the land around it. A description of what might constitute a satisfactorily defined landscape is provided below. The guiding principles defined here are based around two primary broad parameters of any landscape, scale and extent. These parameters define the boundary of a focal study area, the scale and extent of which should be the first consideration of any landscape-scale monitoring programme. These principles have been researched and designed to provide practical guidance, and to highlight the need to be aware of the limitations and constraints that defining landscape boundaries may place on data analysis and interpretation, and the need to explicitly state these caveats in reporting.

| | | |
|---|---|---|
| **1. Defining landscape-scale.** | At a most basic level, landscape-scale might be defined as an extent somewhere between site and national scales. Conceptually this might be visualised as the scale that would include sufficient coherent elements to provide a range of ecosystem services, i.e. water catchment, aspect and topography, varied climatic conditions, sufficient species richness and ecosystem function to allow for multifunctionality of interactions, a variety of habitats, and sufficient area to permit the immigration and emigration of plants, animals, and their vectors. Alternatively, a landscape may be defined as a geographic area in which variables of interest are spatially heterogeneous. The boundary of a landscape may be arbitrarily delineated (i.e. based on project delivery or administrative scales), or functionally delineated (based on ecologically meaningful scales), which are relevant to monitoring questions and objectives.<br><br>The discipline of landscape ecology emphasizes the interactions between spatial patterns and ecological processes, that is, the causes and consequences of spatial heterogeneity at a range of scales[1]. Historically, landscape ecology has focused on large-scale processes, and the term landscape-scale tends to be used for large-scale studies (large-scale defined in ecological rather than cartographic scale). The term landscape is often used to refer to regional, national or continental contexts. It may be more accurate to refer to the scale at which an attribute functions. For example, the spatial structure within landscape can be analysed at a patch level (e.g. individual patches and their variability), class level (e.g. forest, agriculture, urban), or at the landscape level (all classes considered together). Analyses can be conducted at different spatial scales, depending on the processes involved or the species being studied. When linking animal movements and landscape structure for example, home ranges and stocking rates can be excellent proxies to identify scales at which areas of interest (i.e. landscapes) can be defined. | A rule of thumb when determining an appropriate scale at which to define a landscape, is that there should be good correlation between the observed ecosystem process (i.e. connectivity) and the distribution of the population(s) involved. It should take account of the scale at which the focal species or metric operates. For example, small mammals use a landscape at much finer, granular scales than large predatory mammals. As connectivity is dependent on the movement and dispersal ability of a species, often landscape-scale is dependent upon home range.<br><br>In practice it is often likely to be difficult to achieve a satisfactory delineation of landscape boundaries for the analysis of landscape-scale outcomes for landscapes defined by project delivery or administrative areas, rather than ecologically determined boundaries. Defining a study landscape area is strongly dependent on the study objective, and zonation of the classes of interest (i.e. habitat type, extent of management intervention, or area influenced by a policy).<br><br>It is recommended that as far as possible, ecological (i.e. habitat, hydrological, geological, climatic) parameters form the basis of landscape-scale definition for the purpose of assessing conservation outcomes. Where this is impractical, or does not meet specific reporting objectives (i.e. for specific projects, or administrative-scale reporting), then the limitations in the scope of interpretation (see point 2) should be clearly stated in analysis and reporting. These apply both to arbitrarily and functionally delineated landscapes. |

[1] Turner MG, Gardner RH, O'Neill RV (2001) Landscape ecology in theory and practice: pattern and process. Springer, New York





| | | |
|---|---|---|
| **2. Defining landscape extent.** | The extent, and therefore also boundaries, of landscape areas defined arbitrability (i.e. in non-ecological terms) are functionally meaningless in terms of certain attributes one may wish to assess. For instance, dispersal and connectivity happen within the extent of a landscape in which they can function, irrespective of an arbitrarily defined monitoring extent. The functional extent of any defined landscape is contiguous with the land adjacent and with land further afield, and can potentially be functionally connected on much larger scales, including globally (i.e. arctic tern). For instance, assessing landscape connectivity for a species in a landscape in which the habitat(s) in which that species can permeate extend beyond the defined boundary of the landscape being monitored, cannot fully assess how that species responds to conservation intervention. It may permeate in a direction that takes it outside of the monitored area, and this would not be detected by the monitoring programme. | Populations within a landscape are subject to immigration and emigration, and as such changes in demographic parameters within a landscape may be influenced by both factors within and outside of the landscape of interest. For example, a wintering population of black-tailed godwits in a Kentish landscape may be affected by the availability of feeding habitat with the focal landscape, breeding productivity influenced by factors affecting the summer breeding range (Iceland), and other parts of the wintering range (west Africa) and migratory flyway, all outside of the focal landscape. It is important to appreciate what can and can't be linked to conservation action within a landscape, and to define extent, and select metrics and indicators appropriately. Where a focal landscape is defined in non-ecologically delineated terms, such as at project delivery or administrative scales, caveats around interpreting patterns in the data that may be influenced by factors outside of the focal landscape must be clearly stated. In practice this is often likely to apply also to ecologically delineated landscapes in many circumstances.<br><br>It is recommended that as far as possible, ecological (i.e. habitat, hydrological, geological, climatic) parameters form the basis of landscape-extent definition for the purpose of assessing conservation outcomes. |

A satisfactorily defined landscape might be one that encompasses the scale over which the intended conservation outcomes might be expected to manifest, and constrained within the practicalities of resourcing and logistics by an ecologically meaningful spatial extent, such as the extent of a habitat type or landscape character area.

# OP3.3 Ordered list of attributes of monitoring programmes

Here we signpost a very useful piece of work by Pocock et al (2015)[2] that provides an excellent basis for the design of monitoring programmes. Using a collaborative approach involving 52 experts in biodiversity monitoring in the UK, a list of attributes relevant to any biodiversity monitoring programme was developed. These attributes were prioritised and ranked according to their importance for biodiversity monitoring in the UK. The experts involved included data users, funders, programme organisers and participants in data collection, and their expertise encompassed a wide range of taxa. The final list of 25 attributes of biodiversity monitoring schemes developed by the group is provided below, ordered from the most elemental (those essential for monitoring schemes) to the most aspirational. This ordered list provides a practical framework which can be used to support the development of monitoring programmes and can aid in prioritising resources. We believe it is very useful to consider in the context of developing landscape-scale monitoring programmes.

| Rank of importance | Attribute |
|---|---|
| **Most elemental** | Objectives and questions defined |
| | Standardised methods and protocols |
| | Suitable, accurate, efficient sampling methods |
| | Sufficient contributors |
| | Suitable and accessible identification resources |
| | National, regional, or local coordination |
| | Efficient data entry, storage and processing systems |
| | Data is reliable and validated |
| | Results and findings fed back to participants |
| | Sufficient contribution of specialist knowledge |
| | Appropriate analytical and statistical approaches available |
| | Good retention of contributors |
| | Mentoring, training and support for contributors |
| | Analytical and statistical approaches accessible |
| | Change reported at appropriate intervals |
| | Appropriate, scientific, sampling design |
| | Simple reporting of widespread and common species/attributes available to all |
| | Results disseminated widely |
| | Best practice shared between organisations and schemes |
| | Indicator/important species or attributes identified |
| | Wide coverage by participants |
| | Collection of supplementary data (i.e. habitat, soil, weather) |
| | Focus on important species, locations, habitats etc |
| | Electronic data capture |
| **Most aspirational** | Change reported annually |

[2] Pocock, M.J.O., Newson, S.E., Henderson, I.G., Peyton, J., Sutherland, W.J., Noble, D.G., et al. (2015) Developing and enhancing biodiversity monitoring programmes: a collaborative assessment of priorities. Journal of Applied Ecology, 52, 686–695. https://doi.org/10.1111/1365-2664.12423





# OP3.4 Defining monitoring themes and rationale

Landscape-scale outcomes can be categorised into broad themes. To inform and direct monitoring approaches, it is useful to structure a monitoring framework around these themes, to ensure the aims, scope and objectives of monitoring are clearly defined, and to inform the articulation of monitoring objectives, questions or hypotheses. Themes such as the Lawton principles are widely familiar in landscape-scale conservation policy and practice through some outcomes of landscape-scale conservation fall outside of these themes. A critical step in designing any landscape scale monitoring programme is to clearly define the framework in which the monitoring objectives sit. While these principles are familiar to many practitioners and policy makers, they are included here, as a fundamental basis for designing any landscape-scale monitoring programme is to clearly articulate the broad aims of landscape-scale conservation efforts and the resulting outcomes that monitoring aims to detect.

| Theme | Ecological rationale |
|---|---|
| **MORE & BIGGER** | Species confined to small, single, or only a few sites, are unlikely to be adequately protected[3]. Making sites bigger, and having more sites, reduces the risks, and large sites favour more natural processes. It is almost always the case that large areas support more species than smaller areas (the 'species-area relationship'), both because they support larger populations of individual species that are less likely to fluctuate to local extinction, and because they are likely to be more physically variable (in their geology, topology, and variety of habitats), providing greater habitat diversity. Another usually beneficial characteristic of larger sites is that of reduced 'edge effects'. The edges of habitats (for instance a woodland) abutting a more hostile environment (a cereal field for example) often differ markedly in microclimate and other characteristics from the habitat centre. In addition, small patches of grassland may be degraded by nutrient pollution from fertilisers and spray drift from adjacent arable land. These edge effects can penetrate surprising distances into a habitat, making them less suitable for many species and effectively reducing the working size of the wildlife site. For obvious geometric reasons, the proportion of 'edge' decreases with larger sites. All sites do, of course, must have edges and they can be important habitats in themselves particularly when they provide transitional habitats. |
| **BETTER** | The better management of areas of semi-natural habitat is a critical component of landscape-scale conservation[3]. Most semi-natural habitats were created by particular forms of human land-use or now absent natural processes, often over millennia, and hence depend upon ongoing and appropriate management, for example grazing or cutting, to prevent succession and loss of conservation value. This is particularly true for mid or early successional habitats such as grasslands and heathlands which would otherwise succumb to scrub encroachment and eventually become woodland. Many of our rarer species are associated with early or mid-succession stages and disturbed habitats and so management is critical if these species are to be retained. Better management increases local population densities of target species, sometimes by as much as two orders of magnitude, which in turn reduces the risk of local population extinction, provides more colonists for range-expansion and increases the viability of local meta-populations. In the UK's fragmented landscape, with its preponderance of many small wildlife sites, management can mimic the patterns of disturbance and habitat variation that would normally be characteristic of much larger landscape mosaics. Management is at times portrayed as 'gardening' our countryside, but it often represents an effective conservation response, by allowing us to make more efficient use of scarce space to conserve biodiversity and ecosystem services. Indeed, habitat heterogeneity can be more important than site size in determining the species diversity of wildlife sites. |

*cont/d over*

[3] *Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., & Wynne, G.R. (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.*

| Theme | Ecological rationale |
|---|---|
| JOINED | Functional connectivity between core areas of habitat is critical to enabling species to move between them to feed, disperse, migrate or reproduce[3]. Connectivity may come from linear, continuous habitats, or a number of small sites may act as 'stepping stones' across which certain species can move between core areas. Equally, a land mosaic between sites that allows species to move is effectively an ecological corridor. Species' distributions are often dynamic, and many species' populations exist not as spatially isolated groups but as meta-populations, sets of local populations linked by the dispersal and movement of individuals to adjacent populations. Meta-populations have some surprising, but well understood properties. If one or more of the linked patches of habitat are lost, (because habitat is destroyed, or deteriorates through poor management), surviving populations on adjacent patches may decline (and even go extinct), even if surviving patches remain in good condition. Individual populations in a meta-population can 'come and go', like lights blinking on and off. And as the distance between individual populations increases, larger (or better quality) habitats are needed to maintain viable individual populations. The geographic scales over which meta-populations operate vary hugely with the nature of the species under consideration. Species may also be required to move between sites for other reasons, in particular: (i) species whose ranges are expanding or shifting due to climate change, (ii) species using resources that are only temporary in the landscape (such as pioneer plant species or species using seasonal ponds); (iii) species in which the individuals have large ranges; and (iv) species that are migratory or which use different habitats at different stages of their life cycles. Many species need to be able to move for one or more of these reasons. Mobile species require both suitable core habitat patches to move to and they need to be able to move between patches. In some situations this will require physical linkages in the form of corridors and stepping stones, but for others it may be more appropriate to ensure the land between sites – the matrix – is permeable to wildlife, through environmentally-friendly farming techniques. Maintaining fragments of surviving semi-natural habitats in good condition matters, not only for the species and individuals currently within them, but also for those on adjacent habitat patches linked as a meta-population, and for other mobile and wide-ranging species. (b) Connectivity matters. As populations in a metapopulation or of mobile species become more and more isolated, it is harder and harder to maintain them, even with excellent local habitat management. |
| BIODIVERSITY | Trends in biodiversity, the variety and variability of living organisms, at genetic, species, and ecosystem levels, are directly linked to the scale and integrity of landscapes. The species-area relationship is one of the oldest known and most documented patterns in ecology. It describes the general pattern of increase in species richness with increasing area of observation[4]. More, bigger, better and joined spaces are key to sustaining and restoring biodiversity at landscape-scale, but monitoring within these themes alone does not encompasses all of the intended outcomes of landscape-scale conservation. Monitoring trends in biodiversity is a key component in assessing landscape-scale outcomes of landscape-scale conservation. |
| ECOSYSTEM FUNCTION | Ecosystem function is linked to biodiversity, and the relationship between biodiversity and the size, extent, quality and connectivity of landscapes, and is scale-dependant. Bigger, better, more connected landscapes provide and sustain greater, more resilient ecosystem functions. At local scales, ecosystem functioning increases with species richness in a positive but decelerating fashion, and greater diversity is required to maintain ecosystem functioning across the range of environmental conditions present at landscape-scale[5]. Understanding trends in ecosystem function at landscape-scale is a key component in assessing outcomes of landscape-scale conservation. |

[3] *Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., & Wynne, G.R. (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.*

[4] *McGuinness, Keith A. 1984. Equations and explanations in the study of Species–area curves. Biological Reviews 59.3: 423–440.*

[5] *Thompson, P.L., Isbell, F., Loreau, M., O'Connor, M.I. & Gonzalez, A. (undated) The strength of the biodiversity–ecosystem function relationship depends on spatial scale. Proceedings of the Royal Society B: Biological Sciences, 285, 20180038. Royal Society.*





# OP3.5 Prioritised list of key landscape scale questions

A series of workshops were convened by the project at which collectively, 60 conservation practitioners representing 37 UK organisations prioritised by voting for a list of key questions, important to all stakeholders, that will demonstrate the success of landscape-scale conservation.

**Summary of the questions posed to and raised by workshop participants, about landscape-scale outcomes of landscape-scale conservation action, and the result of a vote to prioritise those considered most important**

| Theme | Questions posed (votes) | Questions prioritised by votes |
|---|---|---|
| MORE | Are there more sites for nature? (5) | NA |
| BIGGER | Is the area of habitat/land managed for wildlife increasing? (28)<br>Is the area of key habitat types increasing? (12) | **Is the area of habitat/land managed for wildlife increasing?** |
| BETTER | Is habitat quality improving? (36)<br>Is management practice improving? (7) | **Is habitat quality improving?** |
| JOINED | Is the landscape physically more connected? (8)<br>Is the landscape theoretically more connected? (1)<br>Is the landscape functionally more connected? (43) | **Is the landscape functionally more connected?** |
| BIODIVERSITY | Are there more species in the landscape? (5)<br>Are population sizes increasing? (14)<br>Are species distributions increasing? (21) | **Are species distributions increasing?** |
| Additional questions proposed | How is ecosystem functionality changing?<br>What actions are we taking and where?<br>What are the threats to conservation at landscape-scale?<br>What other factors affect the environment and are they changing?<br>What should we do next?<br>Where do we need new connections/sites/habitats?<br>Are we reducing the factors that are degrading the ecological resistance of Living Landscapes?<br>Which habitats should we be improving or acquiring?<br>What is happening in our landscape and what is the driver? | NA |

# OP3.6 Articulating the question and hypothesis testing

Scientists find answers to questions by testing hypotheses, and conservation practitioners should adopt a similar approach to monitoring biodiversity. All too often monitoring is poorly thought out and specific hypotheses are not defined. Data is collected without defining a question, and yet answering questions is attempted using the data. Any question defined as a monitoring objective must represent a testable hypothesis. It is not possible to know if you have answered the question if one has not been defined or cannot be answered with the data collected.

While complex statistical hypothesis testing may be out of reach of some practitioners, a hypothesis-based approach has several advantages. It defines the topic, the nature of the monitoring objective (e.g. quantify, explain, describe, compare), the specifics of the objective (what, where, how, why, when), the variables (e.g. habitat, management technique) and indicates whether you foresee relationships between variables. It also allows the definition of constraints: what can and cannot be answered, and what is in and out of scope of the monitoring objective. It provides direction, informing the data that are required. It is impossible to define a data collection methodology or approach for a poorly defined question.

A hypothesis is a tentative answer to a scientific question. A testable hypothesis is a hypothesis that can be proved or disproved as a result of testing, data collection, or experience. Only testable hypotheses can be used to conceive and perform a monitoring objective using the scientific method. The null hypothesis (often denoted H0) is a general statement or default position that there is no difference between two measured phenomena or that two samples derive from the same general population. Testing (rejecting or not rejecting) the null hypothesis and thus concluding that there are (or there are not) grounds for believing that there is a relationship between two phenomena (e.g. that landscape-scale conservation has a measurable effect is a central task in the modern practice of science.

Furthermore, in the context of landscape-scale monitoring, this approach can help to break down broad and vague questions such as 'is the landscape better because of landscape scale conservation efforts?' into specific questions about bigger areas of habitat, better quality habitats, and more connected habitat, as well as questions about the components of biodiversity and specific species.

One of the principles behind the scientific method is that any scientific hypothesis and resultant experimental or survey design must be inherently falsifiable. Falsifiability is the assertion that for any hypothesis to have credibility, it must be inherently disprovable before it can become accepted as a scientific hypothesis or theory. Consider these two statements:

- There are wild elephants in Kent.
- There are no wild elephants in Kent.

If your monitoring programme fails to find elephants in Kent, can you be certain there are none? Just because you didn't find one, it doesn't necessarily mean there are none. If you do find an elephant, you are immediately confident that they are present. The second statement is therefore falsifiable, but the first is not. So, the null hypothesis (H0) is that there are no wild elephants in Kent because it can be rejected in favour of the alternative hypothesis (H1) when a wild elephant is found.





**Example testable hypotheses for landscape-scale outcomes of landscape-scale conservation**

| Landscape-scale conservation principle | Landscape-scale outcome themes | Questions | |
|---|---|---|---|
| | | *Broad*<br>Un-testable hypotheses | *Specific*<br>Testable hypotheses |
| **MORE** | Number of sites in conservation management. | a) What is the impact of conservation intervention at landscape-scale? | • Are there more sites for nature?<br>• Is new habitat created? |
| **BIGGER** | Area of land in conservation management. | | • Is the area of land in conservation management changing? |
| **BETTER** | Habitat quality.<br>Management practice. | | • Is habitat quality changing?<br>• Is habitat managed more effectively?<br>• Is habitat restored effectively? |
| **JOINED** | a. Physical connectivity.<br>b. Theoretical connectivity.<br>c. Functional connectivity. | | • Is there a physically more connected matrix of habitat in the landscape?<br>• Does modelling demonstrate that landscape changes support increased connectivity?<br>• Are species, habitats and processes functionally more connected (demonstrated with field data)?<br>• Does increased connectivity lead to better performance of a patch? |
| **BIODIVERSITY** | a. Species richness.<br>b. Species diversity.<br>c. Population size.<br>d. Species distribution. | • What is the current and changing state of biodiversity?<br>• Is there more biodiversity as a result of landscape-scale conservation efforts? | • Are species reintroductions effective?<br>• Are new species colonising?<br>• Are populations increasing in size?<br>• Are species distributions changing? |

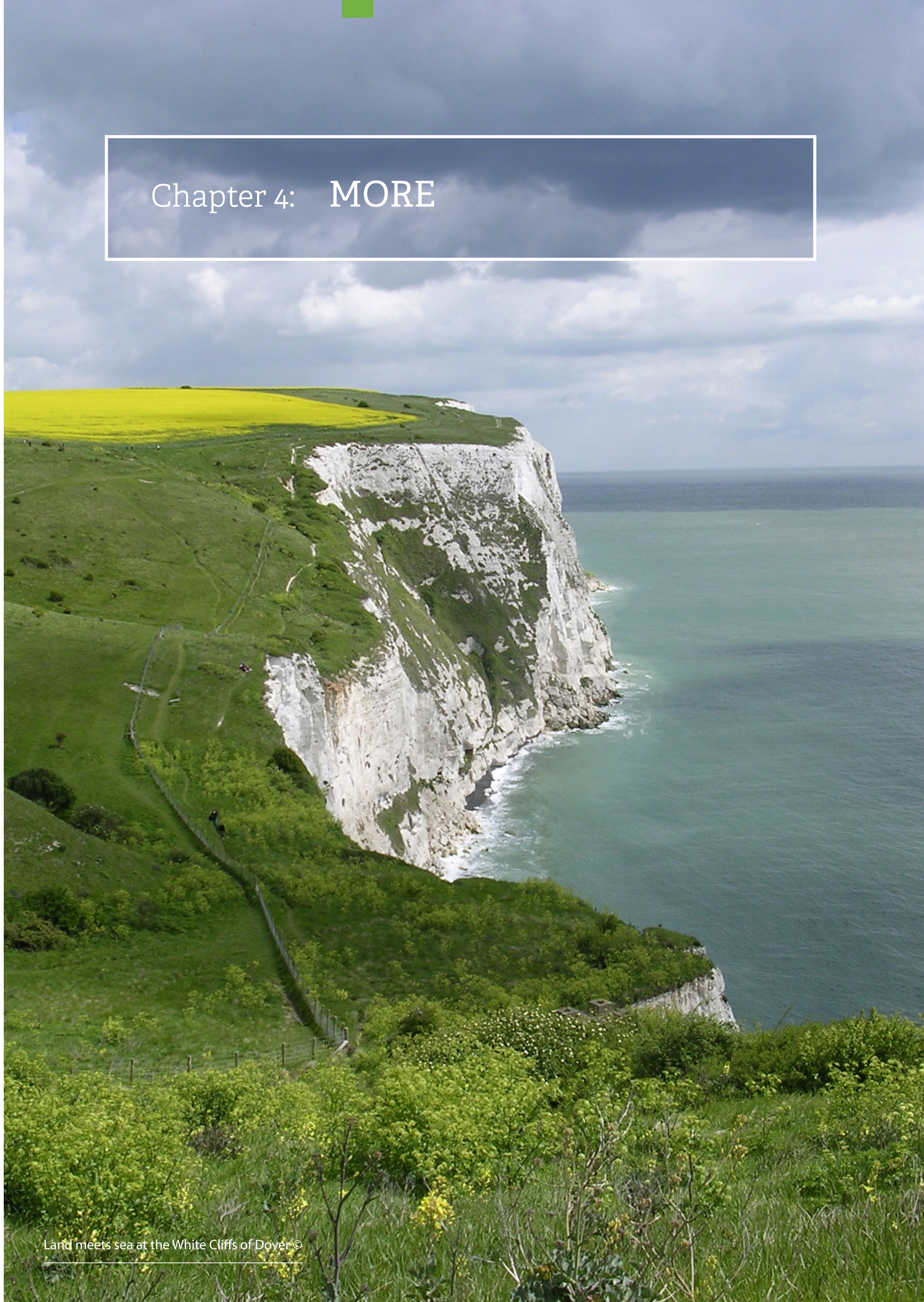
## OP3.7 Criteria for selecting landscape-scale indicator species

A series of workshops were convened by the project at which conservation practitioners representing 37 organisations prioritised, devised and agreed the following criteria for selecting landscape scale indicators. The term "indicator species" has three distinct meanings. 1. They are a species, or group of species, that reflect the biotic or abiotic state of an environment. 2. They reveal evidence for, or the impacts of, environmental change. 3. They indicate the diversity of other species, taxa, or entire communities within an area. Further to these meanings, the criteria below provides a framework for selecting indicator species to specifically address questions about landscape-scale outcomes of conservation. Establishing criteria for selecting indicators, rather than suggesting specific indicators, addresses the concerns raised by stakeholders around future-proofing monitoring approaches and the risk of defined indicator species becoming rare or extinct.

### Criteria for selecting landscape-scale indicator species

- Dispersal mechanism and ecology must be well understood.
- Both population demographics and dispersal must have the potential to be facilitated by conservation actions carried out in the landscape.
- Must be identifiable by surveyors, which might be dependent on skills and experience of the workforce.
- Must be sensitive enough to detect important changes but not so sensitive that signals are obscured by natural variability.
- Must provide information about changes in landscape-scale biodiversity outcomes that are meaningful in the ecosystem of interest.
- Are able to detect changes at appropriate temporal and spatial scales.
- Have a well-understood and accepted known response to the conservation actions carried out.
- Can be measured using a relatively straightforward and cost-effective process.
- Have broad geographic representation across the focal habitat/landscape/ ecosystem.
- Have a degree of habitat specialism, as connectivity for generalist, ubiquitous species is less constrained than for specialists, and therefore less informative.
- Be sufficiently common or abundant to be detected, but not so common that distribution is unrestricted by connectivity.
- Especially useful if they are being measured as part of an existing monitoring system or a protocol that has been developed.
- Can be easily understood by policymakers and conservation practitioners.





Land meets sea at the White Cliffs of Dover ©

# Background and rationale

Increasing the area of land managed for wildlife is inherent in the Lawton principles[1] *more* and *bigger*. Conservationists seek to increase the size of current wildlife sites and create new sites to establish coherent and resilient ecological networks. Among the wide range of different types of statutory and non-statutory sites which support our wildlife, Lawton recognised that there are three tiers comprising 11 types of sites:

- Tier 1 sites are those whose primary purpose is nature conservation and that have a high level of protection (e.g. SSSIs);
- Tier 2 sites are designated for their high biodiversity value but do not receive full protection (e.g. Local Wildlife Sites);
- Tier 3 are landscape designations with wildlife conservation as part of their statutory purpose (National Parks and AONBs).

The hierarchical contribution to the overall quality of networks of sites within each of these tiers has informed the development of our approach. We adopted a similar simple tiered metric of the certainty of management value and action providing a positive influence for wildlife. For example, the value or contribution of a SSSI to a network is more than a field margin in a basic level stewardship scheme, and while both support nature conservation, it is important that landscape-scale assessments of management action, accounts for both the quantity of area managed and the quality and certainty of management.

We know that many wildlife sites are too small and habitat losses are too substantial to halt biodiversity loss. Most semi-natural habitats important for wildlife are insufficiently protected and under-managed, and connectivity in the landscape has been degraded or lost, leading to isolated and fragmented sites. One of the most fundamental steps towards restoring ecological networks at the landscape-scale, is increasing the number and size of the jigsaw pieces. An effective mechanism to measure and monitor this is an essential component of evidencing outcomes of landscape-scale conservation.

Project stakeholders ranked the question *'Is the area of land managed for wildlife increasing?'* as the third most important landscape-scale outcome to assess. They told us they wanted to see more land managed for wildlife and to have more and better data to assess change. While an important aim is to increase the number of sites managed positively, simply monitoring changes in the number of sites, has limited use. For example, one large site may be bigger than ten small ones and of significantly greater value. Thus, the area of land under positive management for wildlife conservation is the most useful metric to assess. We discussed with stakeholders an ideal standardised approach to monitor how much land is managed positively for wildlife.

[1] *Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., & Wynne, G.R. (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.*





# Development

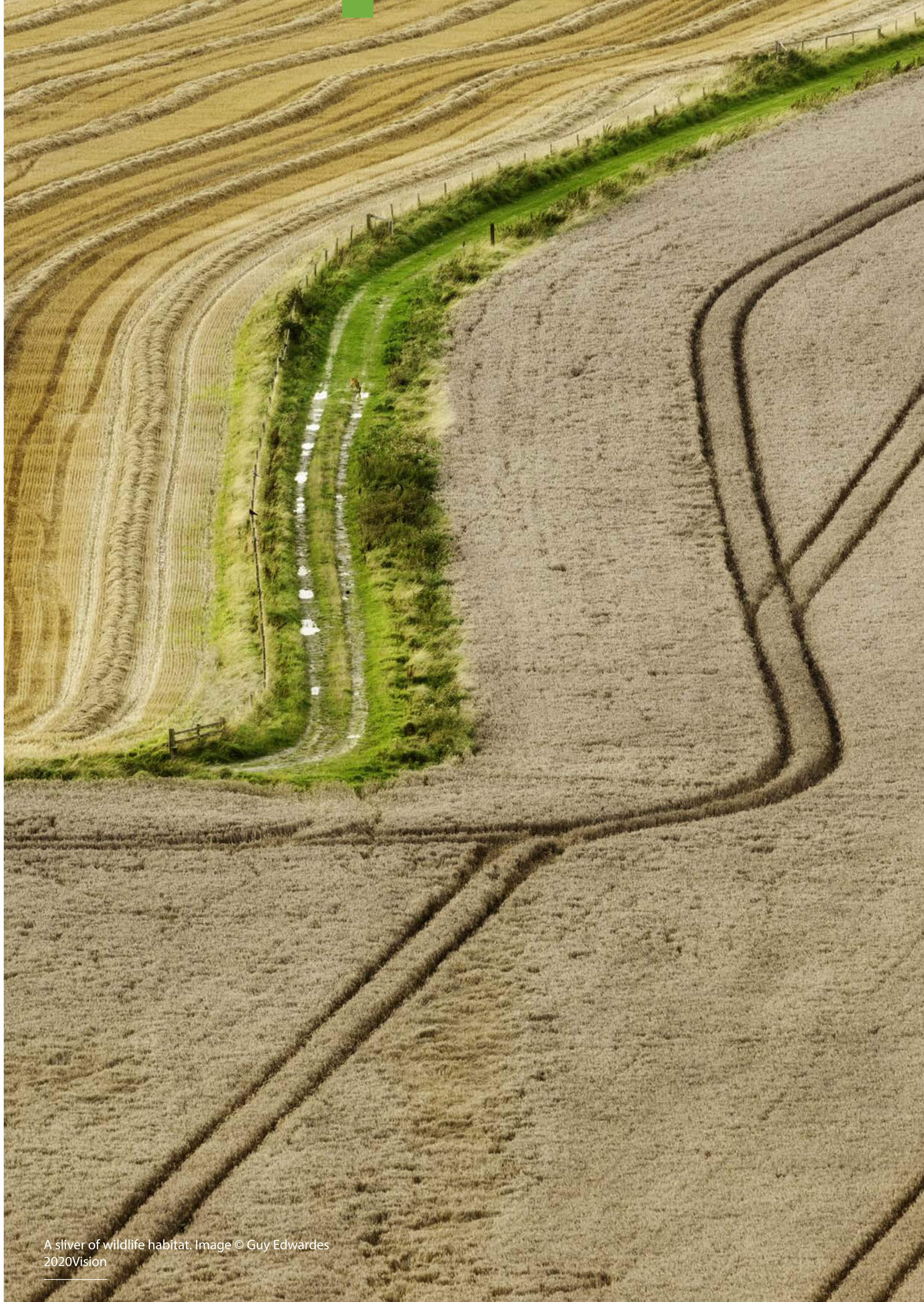
| | |
|---|---|
| **1. Stakeholder contribution** | How stakeholders informed the design of the approach:<br>• Prioritised *area of land managed for wildlife* as a key theme in landscape-scale monitoring.<br>• Specified a desire to see more land managed for wildlife, and a need for more and better data to assess change.<br>• Specified the aspirational attributes, challenges and opportunities of an area managed monitoring tool (Table 4.1).<br>• Development was augmented by a secondary consultation with a small number of stakeholders who already measure the area of land managed for wildlife. |
| **2. Audit and gap analysis** | Kent Wildlife Trust had an existing internal approach to recording the area of land managed for wildlife in Kent, but to provide an effective standardised solution we wanted to ensure this existing approach met the requirements of the conservation community. The project conducted a secondary consultation of key stakeholders to find out if other organisations already had an approach to assessing how much land is managed positively. The consultation reached approximately 300 stakeholders, seven of whom responded with details of their existing approaches. Key features were cross-referenced and combined in our approach.<br><br>Audit and analysis resulted in:<br>• Aspirational attributes, challenges and opportunities of an area managed tool (see Table 4.1).<br>• A comparative analysis of stakeholders' existing approaches (see Table 4.2).<br>• Development of a hierarchy of management categories. |
| **3. Development and testing** | **Principles**<br>Combining the guiding principles provided by project stakeholders, and the features in our own and others' existing approaches, we compiled a comprehensive list of the desirable features for a tool to assess the area of land managed positively for wildlife (see Table 4.4, 4.5, 4.6).<br><br>**Practical approach**<br>Working in partnership with the Kent and Medway Biological Records Centre (KMBRC), we developed new functionality within an existing online GIS tool: Kent's Conservation Landscape Tool (KCLT): https://www.kentwildlifetrust.org.uk/what-we-do/protecting-wild-spaces/kents-conservation-landscape-tool<br><br>KTLC was initially created to replace the withdrawn Biodiversity Action Reporting System (BARS) web map tool in which organisations recorded work undertaken towards Biodiversity Action Plan targets. Recording the area of land in conservation management is also important as a Key Performance Indicator for such documents as Kent's Biodiversity and Environment Strategies.<br><br>• The desirable features from a number of others' approaches were selected and incorporated into a design brief for an effective common approach.<br>• New functionality was developed within the existing KCLT in accordance with the design brief, and in partnership with KMBRC.<br>• The tool was tested and a case study of its use documented.<br>• The design brief is provided as a project output to enable others to recreate the tool in proprietary or opensource GIS platforms. |
| **4. Outputs** | The outputs of this chapter provide a specification and design blueprint to enable others to recreate this process and tool, using either proprietary or open-source platforms, to provide a framework for a common approach to measuring and monitoring how much land is managed for wildlife in any landscape.<br><br>• *OP4.1* **Specification and design blueprint for an area managed tool (Table 4.3).**<br>• *OP4.2* **Case study: area of land managed for wildlife in Kent.** |

# Audit and gap analysis

*Table 4.1* **Aspirational attributes, challenges and opportunities of an area managed tool specified by Nature's Sure Connected stakeholders**

| Platform | Principles | Data sources | Metrics | Challenges |
|---|---|---|---|---|
| • Should use a GIS mapping approach, ideally, an accessible open-source platform. | • Must clearly define what 'managed for wildlife' means.<br>• Incorporate a ranking of management quality and certainty.<br>• Define the types of sites that should be included.<br>• Must provide accessibility of information and data.<br>• Data collection and analysis will need to be reassessed at appropriate intervals. | • Nature reserves, Local Wildlife Sites, SSSIs, environmental stewardship schemes, forestry grant schemes, conservation project areas, advice or management work provided by organisations.<br>• Consult local authorities who already map land management.<br>• Appeal to the public and land-managing organisations for information.<br>• Capture urban and amenity areas. | • Area of land under positive management for wildlife.<br>• Type and scale of management<br>• Management work and/or advice and proof of implementation.<br>• Area of habitat in favourable condition across the landscape including designated and non-designated sites.<br>• Area of core, restoration, new, and/or connected habitat. | • Collecting, digitising and standardizing data from a large and varied suite of sources.<br>• Determine frequency and resourcing of data collection.<br>• Defining which organisation(s) should take ownership and at what scale. |




A sliver of wildlife habitat. Image © Guy Edwardes 2020Vision

MORE
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps | Synthesis and application

*Table 4.2* **Comparative analysis of approaches to quantifying the area of land managed for wildlife at a landscape-scale**

| | Theme | Kent Wildlife Trust | Sussex Wildlife Trust | Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust | Hampshire & Isle of Wight Wildlife Trust | Surrey Wildlife Trust | Environment Agency 'Excel' | Woodland Trust | South East Water |
|---|---|---|---|---|---|---|---|---|---|
| **Platform** | Platform | QGIS for data collection & ArcGIS for some analysis | ArcGIS mostly with some QGIS | ArcGIS Online | MapInfo Pro | MapInfo | Excel | GiSMO | ArcWeb |
| | GIS (data collection and digitising) - some online | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes |
| | GIS (post processing/reporting) - some online | Yes | Yes | Yes | Yes | Yes | No | No | No |
| | Database (for recording) | No | Access Excel | No | Excel | No | Excel | Excel | Access Excel |
| **Data Sources** | Work on own land recorded (parcel by parcel) | Yes | Yes | Yes | No | Yes | No | Yes | Yes |
| | Work on own land recorded (by parish) - NA where calculated from more precise data | NA | NA | NA | No | NA | NA | NA | NA |
| | Work on others' land recorded (parcel by parcel) | Yes | Yes | Yes | No | Yes | No | No | Yes |
| | Work on others' land recorded (by parish) - NA where calculated from more precise data | NA | NA | NA | Yes | NA | NA | NA | NA |
| | Other organisations' work in the county recorded | No | No | No | No | No | No | No | No |
| | Includes private owner contact details (using GDPR[2] compliant methods) | No | Yes | No | No | No | No | No | NA |
| | Includes Marine area recording | Yes | Coastal but not marine | NA | No | NA | NA | NA | No |
| | Habitats on own site | No | Yes | Yes | No | No | No | Yes | Yes |
| | Other GIS layers made available to users (either in GIS project/tool or able to be added by user) | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes |
| **Data layers:** *either used as direct inputs of managed land or to filter prevailing management activities:* | AgriEnv Schemes | Yes | Yes | Yes | Yes | No | No | No | Yes |
| | Woodland Grant Schemes | Yes | Yes | Yes | Yes | No | No | Yes | Yes |
| | Other conservation organisations' sites | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes |
| | Protected sites (marine) | Yes | Yes | NA | Yes | NA | No | NA | Yes |
| | Protected sites (terrestrial) | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes |
| | Ancient Woodland | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes |
| | Priority habitats | Yes | Yes | Yes | Yes | Yes | No | Yes | Yes |
| | Natural England CABA[3] & CLAD[4] data (restricted access & use) | No | No | No | Yes | No | No | No | No |
| **Data recording** | Data added by digitising | Yes | Yes | Yes | Yes | Yes | NA | Yes | Yes |
| | Existing GIS boundaries can be imported (by administrator for Woodland Trust) | Yes | Yes | Yes | Yes | Yes | NA | Yes | Yes |
| | Ability to add links to other documents | No | No | Yes | No | No | NA | No | Yes |
| **Use and advocacy** | Internal KPIs & reporting | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| | Reporting to funders | Yes | Yes | Not yet | Yes | Yes | No | Yes | Yes |
| | Reporting to RSWT | Yes | Yes | Yes | Yes | Yes | NA | NA | No |
| | Single Data List 160[5] reporting (proportion of LWS in management) | Yes | Yes | No | No | No | NA | NA | No |
| | Identify potential partner working | No | Yes | Not yet | No | Yes | No | No | No |
| | Advocacy (e.g. proof of results) | Yes | Yes | Not yet | No | Yes | No | No | Yes |
| | Recording species conservation work | Yes | Yes | Not yet | No | Yes | No | No | Yes |
| | Habitat quality assessment | No | Yes | No | No | Not yet | Yes | No | Yes |

*[3] CABA - Catchment Based Approach*
*[4] CLAD - Customer Land Database.*

*[5] SDL 160 - Single Data List 160 reporting on the proportion of LWS in management.*


Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

# Practical approach: online data gathering

## OP4.1 Specification and design blueprint for an area managed tool

*Table 4.3* **Framework for developing an area managed tool**

| | |
|---|---|
| **Platform options** | Proprietary platform option: ESRI ArcGIS Online web map<br>Open-source platform options[6]: QGIS<br><br>These products are pre-configured combinations of modular products. Some can be used as-is and all of them can be extended to create custom applications:<br>• GeoServer,<br>• MapGuide,<br>• GeoMoose,<br>• GeoDjango,<br>• MapFish .<br>These products are used as modules combined with other tools to create custom applications:<br>• MapServer,<br>• PostGIS,<br>• OpenLayers,<br>• GDAL (Geospatial Data Abstraction Library),<br>• Leaflet. |
| **Recording features** | • Spatial recording is preferred as it is more intuitive and informative than non-spatial data, it also highlights overlapping/adjacent work, and is essential to quantify area.<br>• Online mapping enables multiple users and organisations to contribute to the same map without GIS capability and software of their own (ESRI ArcGIS Online web map apps or open-source options) |
| **Editable layers** | **Layers**<br>• Broad project areas, to record general project/delivery areas (allow overlaps in geometry).<br>• Individual parcel (polygon) based mapping of conservation management actions/parcels (choose whether to allow overlaps in geometry and establish post-processing procedure to avoid duplication of area assessed).<br>• **NB** Some organisations already record management work in GIS and so being able to import existing GIS polygons is a useful feature that facilitates data entry.<br><br>**Editable attributes in layers**<br>• For broad project areas see **Table 4.4** below.<br>• For parcel/polygon-based conservation management actions see **Table 4.5** below. |
| **Additional data layers useful to display within tool** | • Archived layers of previous years' broad project areas and individual field/site data.<br>• Agri-environment Schemes.<br>• Woodland Grant Schemes.<br>• Ancient woodland.<br>• Designated sites including marine where coastal habitats are within reporting area.<br>• Biodiversity Opportunity Areas/landscape designations.<br>• Inspire Land Registry polygons[7] (to enable advised parcels to be identified and digitised accurately). |
| **Post-processing** | • Create *management quality hierarchy* (**Table 4.6**), a tiered assessment scale classifying effectiveness of recorded management interventions.<br>• A simple hierarchy was favoured: 'beneficial', 'useful' or 'uncertain' were chosen. The decision was guided by the DEFRA guidance on which actions are applicable to calculating the Single Data List (SDL) 160 (the proportion of Local Wildlife Sites in management, see **Table 4.6**). For example, any areas categorised as 'uncertain' could easily be excluded from total areas reported, as needed.<br>• A script can be written to apply these categories during a post-processing step.<br>• Post-processing needs to deal with overlaps where two organisations have recorded a different category of intervention on the same area of land, to ensure the most beneficial level is reported. |





*Table 4.4* **Broad project areas layer attribute table fields**

| Proposed Attribute Table Fields | Field info |
|---|---|
| Project name | Text field (used to inform project name drop down in table 4.4) - mandatory * |
| Lead organisation | Text field |
| Partner organisations | Text field |
| Funding organisation | Text field |
| Project description | Text field - mandatory |
| Area (Ha) | Automatic calculation |
| Project type | Drop down list (including maintain/enhance/restore/create distinctions) |
| Project type 2 | Drop down list (as above) |
| Project type 3 | Drop down list (as above) |
| Main habitat type | Drop down list |
| Desired main habitat | Drop down list |
| Contact name | Text field |
| Contact role | Text field |
| Contact organisation | Text field - mandatory |
| Contact e-mail | Text field |
| Contact telephone number | Text field |
| Permission to make public | Drop down yes/no - mandatory |
| Web link | Text field |
| Project start date | Date field or month & year |
| Project end date | Date field or month & year |
| Project status | Drop down active/complete |

**The software used may not enable fields to be set as mandatory but could be indicated with an asterisk highlight the importance of their completion.*

*Table 4.5* **Conservation management parcels layer attribute table fields**

| Proposed Attribute Table Fields | Field info |
|---|---|
| Site name | Text field |
| Project name | Text field but 'N/A' allowed (ideally a dropdown of projects taking place in the county from the Broad Project Areas layer) - mandatory |
| Project name if not in list above | Text field |
| Main habitat type | Drop down list |
| Desired main habitat | Drop down list |
| Additional habitat type | Drop down list |
| Desired additional habitat | Drop down list |
| Target species group | Text field |
| Specific target species | Text field |
| Site protected; no intervention necessary | Drop down yes/no, default is |
| Date | Date field or Month & Year |
| Practical work | Drop down yes/no, default is no |
| Date (practical work) | Date field (or Month & Year) |
| Conservation grazing | Drop down yes/no, default is no |
| Grazing animals | Text field |
| Date (grazing animals) | Date field (could add second date field for end of grazing if need that info) |
| Management plan | Drop down yes/no, default is no |
| Date (management plan) | Date field |
| Agri-env scheme application | Drop down yes/no, default is no |
| Date … | Date field |
| Written advice | Drop down yes/no, default is no |
| Date … | Date field |
| Visit and verbal advice | Drop down yes/no, default is no |
| Date … | Date field |
| Telephone advice | Drop down yes/no, default is no |
| Date … | Date field |
| Month/s of intervention/s in 2020 | Text (useful if just recording year above or if the activity takes place over lengthy period) |
| Contact name | Text field |
| Contact role | Text field |
| Contact organisation | Text field |
| Contact e-mail | Text field |
| Contact telephone number | Text field |
| Permission to make public | Drop down yes/no - mandatory |
| Area (Ha) | Automatic calculation |

[6] https://www.landscapepartnership.org/maps-data/gis-planning/gis-tools-resources/extensions-other-tools/open-source-web-mapping-tools
[7] https://use-land-property-data.service.gov.uk/datasets/inspire/download

*Table 4.6* **Management quality hierarchy**

| Management/Advice Category | Quality Rating | Rank |
|---|---|---|
| Site protected; no intervention necessary (i.e. a nature reserve not requiring annual management action) | Beneficial | 1 |
| Practical work | Beneficial | 1 |
| Conservation grazing | Beneficial | 1 |
| Management plan | Beneficial | 1 |
| Agri-environment scheme (shown on a Natural England scheme GIS layer) | Useful<br>(Beneficial if relevant options, e.g. those provided for SDL160 reporting). | 2<br>(1) |
| Agri-environment scheme (shown on a Natural England scheme GIS layer) | Useful | 2 |
| Visit and verbal advice | Useful | 2 |
| Agri-env scheme application | Uncertain | 3 |
| Telephone advice | Uncertain | 3 |

# OP4.2 **Case study:** Monitoring the area of land managed for wildlife in Kent using the Kent's Conservation Landscape Tool

## Introduction

Kent benefits from an existing editable web map application, Kent's Conservation Landscape Tool (KCLT), created by Kent and Medway Biological Records Centre (KMBRC) for Kent Wildlife Trust using ArcGIS Online. Working in partnership with KMBRC, additional functionality was created within the tool to meet the data recording needs prioritised by project stakeholders, described in OP4.1. Stakeholders in conservation management in Kent were encouraged to contribute spatial data to the tool, including attribute data on management actions. Using this information, management quality ratings were assigned to the data.

The tool can be viewed here: [https://kmbrc.maps.arcgis.com/apps/webappviewer/index.html?id=357464852fe74230ba1c1668736bfae2](https://kmbrc.maps.arcgis.com/apps/webappviewer/index.html?id=357464852fe74230ba1c1668736bfae2)

It is explained here: [https://www.kentwildlifetrust.org.uk/what-we-do/protecting-wild-spaces/kents-conservation-landscape-tool](https://www.kentwildlifetrust.org.uk/what-we-do/protecting-wild-spaces/kents-conservation-landscape-tool)

**1. Define landscape parameters:** the parameters of the study landscape were defined as the entire administrative extent of Kent and Medway as shown in **Figure 4.1**.


*Figure 4.1* **Kent and Medway land target areas for Kent's Conservation Landscape Tool**





**2. Define theme to be addressed:** To quantify the area of land (marine management recording is also supported within the tool) which is influenced positively for wildlife conservation in Kent & Medway. For marine areas this is usually prevention of damaging activities, rather than active management. **See OP3.4 Defining monitoring themes and rationale.**

**3. Articulate objective, question or hypothesis:** the objective of this approach is to determine whether the area of land and sea influenced positively for wildlife conservation is changing as a result of conservation organisations' efforts. It is important to articulate the specific objective, question or hypothesis. **See OP3.6 Articulating the question and hypothesis testing.**

**4. Attributes of monitoring programme: See OP3.3 Ordered list of attributes of monitoring programmes.**

| Attribute | | Comment |
|---|---|---|
| **Most elemental** | Objectives and questions defined | From the outset the objective was articulated. |
| | Standardised methods and protocols | Standardised data collection using web map and defined attribute fields, models and scripts for standardised and automated post-processing and analysis. |
| | Suitable, accurate, efficient sampling methods | Guidance on the data to be entered provided. |
| | Sufficient contributors | All conservation organisations in Kent invited to contribute |
| | Suitable and accessible identification resources | Not applicable. |
| | National, regional, or local coordination | County-level coordination facilitated by Kent Wildlife Trust. |
| | Efficient data entry, storage and processing systems | Standardised data collection using web map and defined attribute fields, models and scripts for standardised data analysis. |
| | Data is reliable and validated | Accuracy of digitising and attribute entry relies on the person submitting but as visible to all inaccuracies can be validated. |
| | Results and findings fed back to participants | Planned publication in the State of Nature in Kent 2021 report. |
| | Sufficient contribution of specialist knowledge | KMBRC (specialists in recording) manage and host the tool, all conservation organisations in Kent invited to contribute. |
| | Appropriate analytical approaches available | Analysis performed by Kent Wildlife Trust GIS team. |
| | Good retention of contributors | The mutual benefit provided by the tool is anticipated to encourage retention. |
| | Mentoring, training and support for contributors | Guidance on the data to be entered provided, contact for further help available. |
| | Analytical and statistical approaches accessible | Reporting methods will be explained. |
| | Change reported at appropriate intervals | Annual reporting is anticipated. |
| | Appropriate, scientific, sampling design | Not applicable. |
| | Simple reporting of widespread and common species/attributes available to all | Not applicable. |
| | Results disseminated widely | KCLT is visible to all (confidential sites hidden), State of Nature in Kent 2021 report will be shared publicly. |
| | Best practice shared between organisations and schemes | NSC framework shares the development of KCLT. |
| | Indicator/important species or attributes identified | Not applicable. |
| | Wide coverage by participants | County-wide participation facilitated. |
| | Collection of supplementary data (i.e. habitat soil, weather) | Includes option to record target habitats and species. |
| | Focus on important species, locations, habitats etc. | Can be selected from the data entered. |
| | Electronic data capture | Yes, online. |
| **Most aspirational** | Change reported annually | County-scale annual reporting is anticipated, tool can support organisational internal reporting. |

**5. Selecting indicator species(s):** Not applicable.

### 6. Practical approach:

The methodology involved the following stages:

1. Create a list of target contributing organisations including contact names where known.
2. Produce one-page information document.
3. Set up email distribution list.
4. Update KWT webpage link to KCLT and relevant text.
5. Contact contributors, providing:
   - Information document,
   - Instructions & link to tool,
   - Advice on tool use and data contribution.
6. After the data entry deadline, extract data for the reporting year.
7. Apply 'spaghetti and meatball' technique in GIS to remove overlaps and concatenate values.
8. Derive management quality ratings from data attributes, retaining highest ratings.
9. Calculate geometric areas based on variables of interest (e.g. quality rating, organisation, designation type).
10. Calculate total area of land managed for wildlife in Kent and Medway.

### a. Data submission to Kent's Conservation Landscape Tool

Contributors could submit two types of data; 'broad project areas' and 'conservation management parcels', the latter being more discretely related to practical management activities. This enabled contributors to delineate both the land within a funded project's boundary and the land under active conservation management. These differences were recognised to avoid broad project areas passing as land under management, and thus overestimating area managed, and support the original aim of the tool in enabling the conservation community to view and collaborate across broad project areas.

We created attribute tables for the recorded features, as shown in **Tables 4.4** and **4.5** with either drop-down or yes/no fields, to ensure the data capture in a standardised format to improve comparability and ease of analysis. Although not possible in the initial version of the tool, mandatory fields would ensure essential data was always collected. Fields for contact details enabled users to identify and contact potential partners for any new geographically- or theme-based projects and meant data issues could be followed up. Overlaps in digitised intervention areas were permitted to gather data on multiple actions taking place on one site and resolved in post-processing to prevent double counting.


*Screenshot of the Kent Conservation Landscape Tool showing some areas of land and sea added by stakeholders.*

### b. Post-processing and analysis

To monitor change in the area of land managed for conservation in Kent, the data gathered through the KCLT was supplemented with current (2020) protected area boundaries data and compared with data collected as part of the Kent Biodiversity Strategy mapping exercise, conducted by Kent Wildlife Trust in 2016. Thirteen protected areas datasets (SPA, SAC, SSSI, LWS, KWT reserves, RSPB reserves, LNR, NNR, Plantlife reserves, Woodland Trust reserves, RNR, English Woodland Grant Scheme, and Higher Level Stewardship) from 2016 and 2020 were compared in an overlay analysis. Given their protected status, these areas were assigned a management hierarchy code of 1. Note, only Higher Level Stewardship polygons with options pertaining to 'maintenance' and 'restoration' were retained.





The 'spaghetti and meatballs[2]' approach was applied to the KCLT data, to split overlapping polygons and concatenate all the values from the data fields pertaining to management. In this new flattened layer, hierarchy codes were then derived from the concatenated values, as per Table 4.6. The highest quality ratings were retained in overlapping areas (concatenations). The area of land (ha) for each management quality rating (and land without a quality rating due to insufficient attribute data) was then calculated. The area of land from the KCLT dataset outside of areas with statutory designations was also calculated to understand how much additional land management information the tool had provided.

The KCLT will also enable selections of the data applicable for Single Data List 160 reporting to be made simply, according to its eligibility guidelines for the land management advice included. If conservation organisations working in Kent contribute data to the KCLT, they will then not have to additionally tell KWT about their work on Local Wildlife Sites for it to be included in this reporting, saving time and effort on reporting. KCLT is also being used as the data gathering mechanism for the State of Nature in Kent 2021 report.

### Results

The 13 datasets of terrestrial areas with statutory designation in 2020 covered 70,368 hectares of land. The data entered into the KCLT for 2020 with overlaps removed was 10,763 hectares or 2.8% of the land area of Kent and Medway (373,600 ha total). The KCLT provided information about an additional 1,266 hectares of land managed positively for conservation which fell outside of areas with statutory designation. A comparison of the 2016 (Kent Biodiversity Strategy mapping) and 2020 data of areas with statutory designation showed an increase in protected land area from 62,267 hectares to 70,368 hectares. Based on this data, we see that the total area of land under some form of conservation management in 2020 was 71,634 hectares, or 19.17% of Kent's terrestrial land area.

*Table 4.7* **Land area (ha) and percentage of Kent land surface covered by the 2016 areas with statutory designation, 2020 areas with statutory designation, the KCLT data and the KCLT data outside areas with statutory designation.**

| Dataset | Area (ha) | Percentage of Kent land surface (%) |
|---|---|---|
| 2016 areas with statutory designation | 62,267 | 16.7 |
| 2020 areas with statutory designation | 70,368 | 18.8 |
| KCLT data | 10,763 | 2.8 |
| KCLT data outside areas with statutory designation | 1,266 | 0.4 |

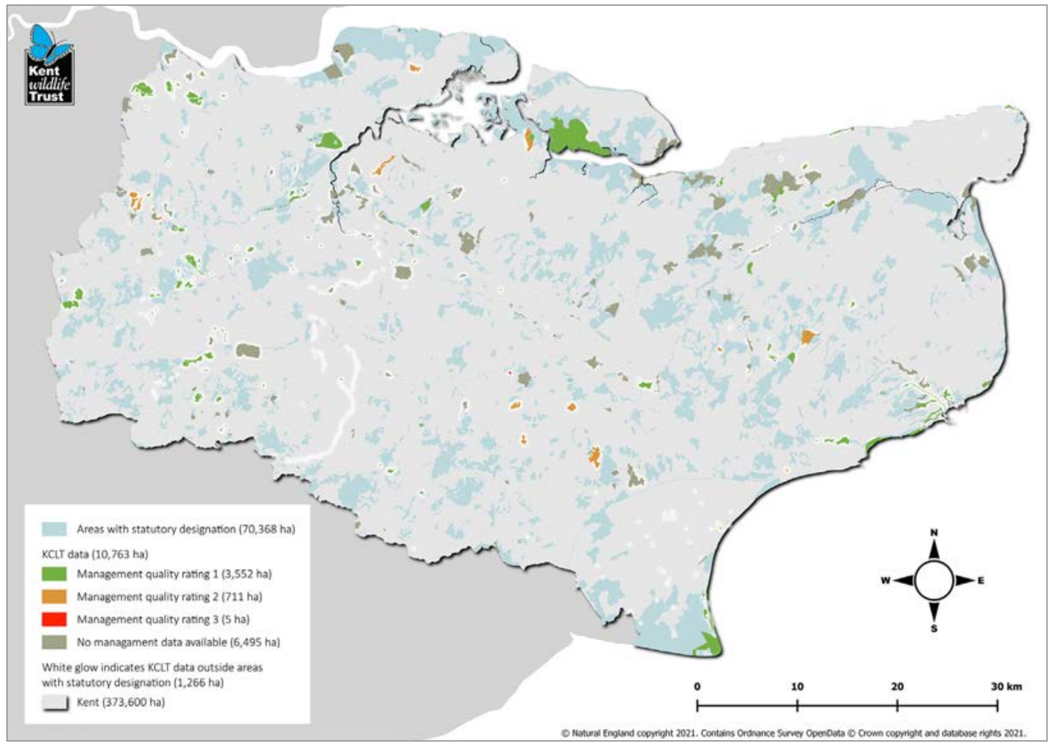



*Figure 4.2* **The terrestrial areas with statutory designation in 2020 and data gathered using the Kent Conservation Landscape Tool for 2020 showing the management quality ratings.**

[2] *Din, A. (2020) Applying Spaghetti and Meatballs to Proximity Analysis. Cityscape, 22, 133–148. US Department of Housing and Urban Development.*

# Limitations

One of the major limitations encountered in the application of the tool was the low engagement by stakeholders in the process of data contribution. Of the 70 organisations approached, 25 (35.7%) provided data in some form. Therefore, we suspect that the results substantially underestimate the area of land influenced for conservation in Kent. To effectively monitor conservation management action in Kent, high engagement by stakeholders is required on an annual basis. Whilst engagement with the tool was lower than expected, there was high availability of GIS layers of land with statutory designation from various organisations. During the stakeholder consultations, concerns were raised over recording sensitive or confidential management work or advice, and so contributors were asked to send sensitive data directly to KMBRC, rather than inputting the data in the online tool.

# Next steps and recommendations

- Repeat the data collection and analysis annually to monitor how the area managed for wildlife changes over time.
- Collaboratively agree the point at which advice or practical work times out. For SDL 160 it is 5 years after one-off advice was provided or after a management plan or grant scheme ends.
- Development of an automated GIS geoprocessing model, for fast standardised analysis of the data.
- Encourage more conservation organisations to input data regularly, so data is gathered across the county on an annual basis for monitoring. Ongoing work by Kent Wildlife Trust is addressing this.
- Encourage others to adopt this approach, build tools, and align reporting of areas managed using a common approach across counties to gain comparable statistics.
- Although not possible to implement in the initial version of the tool, mandatory fields would ensure essential data is always collected.

# Synthesis and application

The approach developed by the project successfully facilitated data collection from multiple stakeholders at the county-scale and quantified an increase in the area of land managed positively for nature - a key intended outcome of landscape-scale conservation. A blueprint for the tool developed by the project that can be recreated by others in open source and proprietary GIS platforms, to gather similar landscape-scale data on a regional basis is provided. This approach has potential application throughout the conservation community. Through continued refinement of the methods in collaboration with others, the practice and practicalities of quantifying how much land is managed positively for wildlife can be advanced. If other organisations can be encouraged to adopt this approach, develop it further to suit their needs, and to share developing best practice with the conservation community, the tool can facilitate the quantification of conservation management actions across landscapes at a national scale.



# Chapter 5: BETTER

Image © Ben Hall 2020VISION

# Background and rationale

The Lawton principles highlight better management and enhancing habitat quality as a key focus for landscape-scale conservation, and this theme was prioritised by project stakeholders. Consequently, detecting and quantifying changes in habitat quality at landscape-scales is a desirable approach in the assessment of the outcomes of landscape-scale conservation. Monitoring habitat quality is typically done at site-scale by surveyors recording the presence and absence of indicator species and physical attributes of habitat condition. These traditional site-scale approaches, such as rapid assessment and habitat condition monitoring, work well for their intended purposes, but scaling-up these approaches to landscapes is often challenging.

One solution to combat the scaling-up issue is to stratify sampling using habitat condition monitoring protocols across landscapes. This has been trialled by others, and a case study of this type of approach in the West Berkshire Living Landscape is included in this chapter. The approach uses volunteer field surveyors who survey randomly selected sample grid squares, stratified across the habitats present. However, field survey techniques may be impractical or sub-optimal at a landscape-scale due to the inability to achieve complete coverage, high resource requirements and access limitations. A field survey approach to landscape-scale habitat quality monitoring may therefore be unable to detect change everywhere it might occur. The project sought to investigate how large-scale landscape-scale monitoring of habitat condition metrics might be achieved. Having assessed the options and reviewed others approaches, the opportunities presented by developing and disseminating experience in remote sensing were recognised.

Remote sensing has the potential to provide a cost-to-scale effective tool for the collection of information needed to evaluate impacts on ecological systems, set conservation priorities, and develop conservation plans. It offers opportunities to reduce costs and potentially provide a sustainable approach to data collection over large areas. It can be used to measure and monitor land cover, land use, vegetation characteristics, terrain, soils, waterbodies, wetlands, marine and coastal environments, atmosphere and climate, disturbance (e.g. fires and floods), landscape fragmentation, human-environment interfaces, urban change, and protected areas. It is a fast-moving technology and investigating its potential application to assessing landscape-scale outcomes in relation to habitat quality and other metrics offered an opportunity to increase and enhance organisational capacity to deliver and evidence conservation at all scales.

Remote sensing is not a complete habitat quality assessment solution however, with some remote sensing relying on very expensive equipment which can be difficult, costly and even dangerous to use and maintain. Some remote sensing work may be prohibitive in terms of cost and resource, however there are many aspects that might be pursued to develop accessible monitoring solutions, especially given the increasing availability of remote sensed data, equipment and training. This project recognised that there are economies of scale that could be achieved by working collaboratively and by developing and sharing expertise and knowledge with stakeholders.

### What is habitat quality?

A wide range of attributes are commonly used to assess the quality or condition of habitats, including extent, botanical composition, vegetation structure and physical characteristics. Floristic and vegetative attributes are generally used as indicators, and assessment of condition may be based on suitable conditions for plants, or both plants and animals. Quality assessment may also consider animal species assemblages. Guidance is provided both by Common Standards Monitoring[1] and the Wildlife Trusts 'Wild Surveys' initiative (**Table 5.1**) for example. Here we focused solely on structural, vegetative and floristic attributes as metrics of habitat quality, for which remote sensing technology offers accessible solutions and general and widespread applicability across a broad range of habitats, to maximise the relevance of project outputs to project stakeholders.

[1] https://jncc.gov.uk/our-work/common-standards-monitoring/





Image © Gillian Day

BETTER
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps & recommendation | Synthesis & application

*Table 5.1* **List of priority taxa groups and mapping against key habitats[2] ranked by usefulness for assessing habitat quality in number of habitats**

| Focal Taxa | Woodland (broadleaf and conifer) | Carr and wet woodland | Parkland | Dry heaths and moors | Wet heaths and bogs | Fens and marshes | Wet grassland | Saltmarsh | Neutral grassland | Calcareous grassland | Dry sandy grassland | Arable | Riverine sand and shingle | Slow moving and standing water | Flowing water | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flowering plants | High | High | | High | High | High | | High | High | High | High | High | High | High | | 12 |
| Ground beetles (Carabids) | | High | | High | High | High | | High | High | High | | High | High | | | 9 |
| Breeding birds | High | High | | High | | High | High | High | High | | | High | | | | 8 |
| Hoverflies | High | High | | | High | High | High | | | High | | | | | | 6 |
| Larger spiders | High | | | High | High | High | | | | | High | | High | | | 6 |
| Dragonflies and damselflies | | | | | High | High | | | | | | | | High | High | 4 |
| Terrestrial heteroptera | | | | High | High | | | | High | | High | | | | | 4 |
| Leaf beetles (Chrysomelids) | | High | | | | | | | High | High | | | | | | 3 |
| Diving beetles (Dytiscids) | | | | | High | High | | | | | | | | High | | 3 |
| Aquatic heteroptera | | | | | High | High | | | | | | | | High | | 3 |
| Lichens | | | High | High | | | | | | | | | | | | 2 |
| Butterflies and day flying moths | High | | | | | | | | | High | | | | | | 2 |
| Macro-moths | High | High | | Possible | | | | | | | | | | | | 2 |
| Ants | | | | High | | | | | | | High | | | | | 2 |
| Solder and click beetles | High | | | | | | | | High | | | | | | | 2 |
| Aquatic molluscs | | | | | | High | | | | | | | | High | High | 2 |
| Saproxylic assemblage | | High | High | | | | | | | | | | | | | 2 |
| Bracket fungi | Periodic | | High | | | | | | | | | | | | | 1 |
| Sphagnum | | | | | High | | | | | | | | | | | 1 |
| Solderflies | | | | | | | High | | | | | | | | | 1 |
| Longhorn beetles (Cerambicids) | High | | | | | | | | | | | | | | | 1 |
| Click beetles (Elaterids) | High | | | | | | | | | | | | | | | 1 |
| Terrestrial molluscs | High | | | | | | | | | | | | | | | 1 |
| Reptiles | | | | Possible | | | | | | | Possible | | | | | 2 |
| Othoptera | | | | Possible | | | | | | Possible | | | | | | 2 |
| Bryophytes | Periodic | | | | | Periodic | | | | Periodic | Periodic | Periodic | | | Periodic | 6 |
| Craneflies | | Periodic | | | Periodic | | Periodic | | | | | | | | | 3 |
| General invertebrate survey | | | | | | Periodic | | | | | | | | Periodic | Periodic | 3 |
| Bats | Periodic | Periodic | | | | | | | | | | | | | | 2 |
| Fish | | | | | | | | | | | | | | Periodic | Periodic | 2 |
| Hymenoptera/other aculeates | | | | Periodic | | | | | | | Periodic | | | | | 2 |
| Waxcaps/old meadow fungi | | | | | | | | | Periodic | | | | | | | 1 |
| Amphibians | | | | | | | | | | | | | | Possible | | 1 |
| Micro-moths | | | | | Periodic | | | | | | | | | | | 1 |
| Staphylinids and selected diptera | | | | | | | | | | | | | Periodic | | | 1 |
| Snails | | | | | | | | | | Periodic | | | | | | 1 |

[2] *Adapted from WildSurveys: A common framework for systematic monitoring of the temporal trends and responses of wildlife to habitat creation, restoration and management within Living Landscape schemes and on Wildlife Trust reserves.*

Image captured from survey as part of UAV flight training, Ham Fen, Kent.



# Development

| | |
|---|---|
| **1. Stakeholder contribution** | How stakeholders fed into the design of the approach:<br><br>• Prioritised habitat quality as a key theme for landscape-scale monitoring to address.<br>• Identified and provided examples of existing approaches. |
| **2. Audit and analysis** | Through desktop research the project reviewed existing approaches to habitat quality assessment, produced a comparative assessment of these approaches and the suitability of their application at landscape-scale, and researched case studies of approaches applied in practice. |
| **3. Development and testing** | **Principles**<br>The following principles were adopted in development and testing, informed by the outcomes of the stakeholder consultation and audit and analysis phases:<br><br>• A focus on remote sensing, perceived to provide the most appropriate cost-to-scale effective approach to develop.<br>• Acceptance of a loss of species-level determination of habitat quality attributes at increasing spatial scale.<br><br>**Practical approach**<br>The following steps were undertaken in the development of a practical approach, and resulted in project outputs designed to offer guidance and solutions to stakeholders, and facilitate progress towards common approaches:<br><br>• Research into equipment and software options, assessment of the pros and cons of different options, and costs involved.<br>• Production of guidance for choice of equipment, software, training and legislative requirements.<br>• Procurement of remote sensing equipment with which to trial an approach.<br>• Staff training.<br>• Field survey using Unmanned Aerial Vehicle-based (UAV or 'drone') remote sensing approach and the production of a case study. |
| **4. Outputs** | The outputs of this chapter are designed to: a) provide an overview of approaches to habitat quality monitoring to aid others to select scale-appropriate methods, b) provide an overview of the requirements for developing a remote sensing approach to habitat quality monitoring at landscape-scale, and c) provide a case study of a real-world example of remote sensing used at landscape-scale.<br><br>• *OP5.1* **Comparative assessment of existing approaches to habitat quality monitoring using floristic and vegetative attributes at landscape-scale.**<br>• *Case study* - **Assessing the effectiveness of a landscape scale monitoring scheme in West Berkshire.**<br>• *OP5.2* **Comparative assessment of the questions remote sensing can answer and appropriate sensors**.<br>• *OP5.3* **Comparative assessment of UAV equipment options**.<br>• *OP5.4* **Comparative assessment of software options.**<br>• *OP5.5* **Comparative assessment of UAV training options.**<br>• *OP5.6* **Comparative assessment of UAV insurance options.**<br>• *OP5.7* **Case study – West Blean and Thornden Woods: digital surface modelling to assess structural attributes of habitat condition.** |

BETTER
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps & recommendation | Synthesis & application

# Audit and gap analysis

## OP5.1 Comparative assessment of existing approaches to habitat quality monitoring using floristic and vegetative attributes at landscape-scale

| Method and description | Strengths | Weaknesses | Suitability for landscape-scale monitoring |
|---|---|---|---|
| **Fixed quadrats**<br><br>Location of quadrats initially randomised, position fixed and surveyed repeatedly over time. Percentage cover of each species and associated ecological attributes recorded. | • Fewer samples required to detect change than random non-fixed method.<br>• Subtle changes detected.<br>• Repeatable.<br>• Potential to link to fine scale abiotic data (e.g. hydrology).<br>• Powerful statistical analysis possible.<br>• Quantifies species presence richness and diversity.<br>• No legislative requirements. | • Resource intensive.<br>• Can be logistically challenging to fix and re-locate positions.<br>• Species ID skills becoming less common within conservation community, may become comparatively expensive.<br>• Scaling up to landscape-scale inefficient. | • Unsuitable: too resource intensive to be practical at landscape-scale. |
| **Random quadrats**<br><br>Locations of quadrats randomised at every survey interval. Percentage cover of each species and associated ecological attributes recorded. | • Subtle changes detected.<br>• Repeatable.<br>• Potential to link to fine scale abiotic data (e.g. hydrology).<br>• Powerful statistical analysis possible.<br>• Quantifies species presence, richness and diversity.<br>• No legislative requirements. | • Larger number of quadrats required to detect change than fixed method.<br>• Resource intensive.<br>• Species ID skills becoming less common within conservation community, may become comparatively expensive.<br>• Scaling up to landscape-scale inefficient. | Unsuitable: too resource intensive to be practical at landscape-scale. |
| **Condition assessment** (Structured walks)<br><br>A course abundance scale (i.e. DAFOR or presence/absence) in a fixed number of quadrats over a structured route, recorded for habitat specific indicator species and attributes. | • Good general coverage at the site-scale.<br>• Repeatable.<br>• Identifies broad changes in vegetation.<br>• Volunteer friendly.<br>• Quantifies some elements of species presence richness and diversity.<br>• No legislative requirements. | • Very coarse discrimination between levels of condition, subtle changes not detected.<br>• Designed for site, not landscape-scale application.<br>• Limited scope for statistical analysis.<br>• Does not measure species richness, diversity etc. or allow community-based environmental change assessment.<br>• Scaling up to landscape-scale inefficient. | Unsuitable: too resource intensive to be practical at landscape-scale, lack of analytical power. |
| **Grid-square mapping using condition assessment criteria**[3] | • Subtle changes detected.<br>• Repeatable.<br>• Potential to link to fine scale abiotic data (e.g. hydrology).<br>• Powerful statistical analysis possible.<br>• Can be scaled to site extent and resource availability.<br>• Whole site coverage.<br>• Quantifies some elements of species presence, richness and diversity.<br>• Volunteer-friendly.<br>• No legislative requirements. | • Resource intensive.<br>• Scaling up to landscape-scale inefficient.<br>• Does not measure species richness, diversity etc. or allow community-based environmental change assessment. | Unsuitable: too resource intensive to be practical at landscape-scale. |
| **Stratified random sampling**<br><br>(See case study[4]) | • Quantifies some elements of species presence richness and diversity.<br>• Repeatable.<br>• Potential to link to fine scale abiotic data (e.g. hydrology).<br>• Powerful statistical analysis possible.<br>• Can be scaled to site extent and resource availability.<br>• Whole site coverage.<br>• Quantifies some elements of species presence, richness and diversity.<br>• Volunteer friendly.<br>• No legislative requirements. | • Resource intensive.<br>• Patchy coverage.<br>• Does not measure species richness or diversity across all taxon groups, or allow community-based environmental change assessment.<br>• Evidence of detection of change not yet conclusive.<br>• Sample size required appears to be larger than has been tested. | May be suitable at smaller landscape-scales. |
| **Remote sensing**<br><br>Unmanned Aerial Vehicle (UAV / drone) technology | • Extensive coverage.<br>• Advancing technology.<br>• Flexible and efficient.<br>• Repeatable.<br>• More frequent repeatability than field survey approaches.<br>• Potential to link to fine scale abiotic data.<br>• Can provide data in a consistent, objective manner.<br>• More cost-scale efficient than field survey.<br>• Powerful statistical analysis possible.<br>• Quantitative at site and landscape-scale.<br>• Can be scaled to size of landscape and resources.<br>• Very high resolution (~4 cm) possible. | • Limited range of habitat quality attributes can be quantified.<br>• Cannot quantify species presence, richness and diversity.<br>• Legislative and training requirements can be arduous and costly.<br>• Equipment can be expensive.<br>• Specialist technology and personnel required.<br>• Battery life can be a limiting factor.<br>• Some locations can be difficult to access safely.<br>• Limits to application at larger landscape-scales. | Suitable: Useful for on demand monitoring of relatively small landscape areas. |
| **Remote sensing**<br><br>Satellite imagery / earth observation | • Very extensive coverage.<br>• Advancing technology.<br>• Flexible and efficient.<br>• Repeatable.<br>• More frequent repeatability than field survey appraoaches.<br>• Potential to link to fine scale abiotic data.<br>• Can provide data in a consistent, objective manner.<br>• More cost-scale efficient than field survey.<br>• Powerful statistical analysis possible.<br>• Quantitative at site and landscape-scale, up to global scale.<br>• Can be scaled to size of landscape and resources.<br>• Improving availability and quality of open-source data.<br>• Free from any controlled airspace limits on UAV use. | • Limited range of habitat quality attributes can be quantified.<br>• Cannot quantify species presence, richness and diversity.<br>• Cloud cover can limit usefulness of data.<br>• Limitations imposed by resolution (~20 m) of satellite data.<br>• Some limitations for monitoring imposed by temporal resolution (acquisition frequency). | Suitable: useful monitoring of very large landscapes up to county, country, and global scales. |

[3] *Meakin, K. & O'Connell, M.J. (2018). Obstacles to gathering conservation evidence from the monitoring of nature reserves: a spatial solution? Ecological Informatics 47: 14–16.*
[4] *Case study: Assessing the effectiveness of a landscape scale monitoring scheme in West Berkshire, within this chapter.*

# **Case study:** Assessing the effectiveness of a landscape-scale monitoring scheme in West Berkshire

*Debbie Lewis, Ecology Manager, Berkshire, Buckinghamshire & Oxfordshire Wildlife Trust*

## Introduction

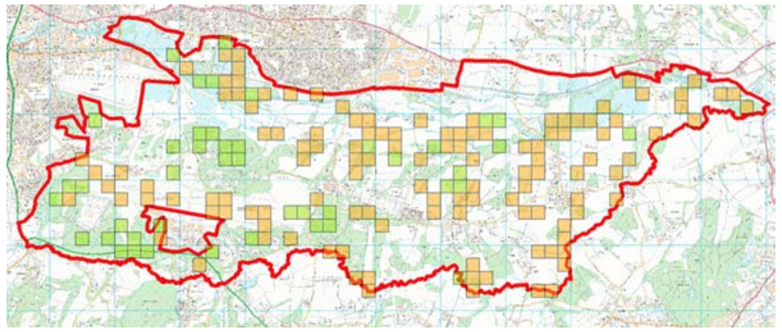
Between July 2013 and January 2019, the National Lottery Heritage Fund supported a 5-year landscape-scale project, focused on a 2600 ha area in West Berkshire[3]. The project included community engagement, practical habitat management and ecological monitoring. At the time of developing the project, little or no monitoring had taken place at landscape-scale. The project aimed to assess both the actual wildlife benefits which had been delivered, albeit in a limited way given the short timescale, and the effectiveness of using the strategy for monitoring at the landscape-scale.

## Monitoring approach

The landscape was subdivided into 200m$^2$ grid squares. Underlying habitat data was used to assign each of these squares to a core habitat type: woodland, wetland, heathland and the interlinking matrix/farmland. Urban areas were excluded. Squares for surveying were randomly selected, stratified by the cover of these core habitats across the landscape as a whole and also by locations where management activity had taken place.

Within each sample square a habitat condition assessment was carried out, using the assigned core habitat as starting point, the surveyor selected an appropriate sub-habitat recording form to use. For example, a 'wetland square' had forms for reedbed, running water, swamp and open water. Each condition assessment included a check list of positive and negative indicator species and physical characteristics, which were recorded at ten stops on a 'w-walk' across the sample square. A range of fauna groups, appropriate to the core habitat were also surveyed. These groups were birds, bats, butterflies, dragonflies, herpetofauna, pollinators and dormice. The majority of fauna groups were surveyed using a 200m straight line transect and national protocols, such as the Pollard Walk for butterflies. Surveys were repeated two to four times during the survey season. Where possible, squares were surveyed twice during the five years to assess differences.

*Volunteers learning how to carry out a habitat condition assessment*



*200m² grid squares surveyed and ground-truthed for habitat condition as part of the West Berkshire Living Landscape Project. Green squares were in conservation management, orange squares were not in conservation management, n=166, Ordnance Survey © Crown Copyright 2016, all rights reserved, license number 100026443.*

[3] https://www.bbowt.org.uk/sites/default/files/2019-12/Linking%20the%20Landscape%20Project%20Report%202019.pdf





## Data analysis

Relative quality values were assigned to the resultant survey data. Different characteristics would add to or remove from the overall 'value' of each survey square. The resulting score would fit into a bracket, ranging from unfavourable condition, through low and medium, to high quality condition. Most habitat condition assessments were done twice - so the 'before' (survey year 1 and 2) and 'after' (years 3 and 4) scores were compared. Year 1 surveys were repeated in year 3, and year 2 in year 4 to allow for some change over the project timeframe. Areas tagged with 'in conservation management' were then compared to those tagged with 'not in conservation management', with correlation determined by R2 values.

## Results

Overall a small positive change in habitat condition was observed for areas in conservation management compared to those not under conservation management. Reedbed habitats showed the most noticeable change, while heathland exhibited a decline. It is assumed that declines related to the short timeframe of the project; many habitats require a longer timeframe than 5 years to return to favourable condition post management. Similarly, as might be expected, the species data showed very little change in abundance, or presence of key species over the 5 years.

## Discussion

The limited difference seen in the habitat condition and species data, after the completion of the five-year project, emphasises the importance of long-term, sustainably resourced monitoring, if real differences following landscape scale conservation are to be evidenced. When considering the monitoring strategy used there were some useful lessons learned, which could inform future landscape scale monitoring. Using stratified (by core habitat), randomly selected sample squares worked well, and mirrors the strategy employed by national monitoring schemes. The West Berkshire Living Landscape was a relatively small area, and 200m$^2$ sample squares proved to be too small to reliably sample many of the key fauna species due to habitat heterogeneity within this area, limiting the number of different key fauna that could be surveyed for. In a bigger landscape, a 1km$^2$ would be a more appropriate sample size, as this will allow the assessment of all features and habitats of interest, rather than the main habitat. A smaller sub-set of key fauna groups is also likely to be more sustainable in the long term, given the complexity of some species groups to identify, such as pollinators and the amount of survey effort required to sample a large number of squares, for a large range of species. Habitat condition assessments proved useful as a quick way of generating a snapshot of condition for ongoing comparison. The biggest challenge was ensuring that volunteers with less experience selected the correct sub-habitat form, or indeed the correct top-level habitat form, if the underlying habitat data proved incorrect on the ground. This protocol also required a substantial amount of initial time investment in the creation of generic forms, which had to be ecologically informative, based on local species, but without having an impossibly long list of options.

## Future landscape-scale monitoring

Following the completion of the West Berkshire Project the Chilterns AONB approached Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust, together with Centre for Ecology and Hydrology, Plantlife, Butterfly Conservation (BC), British Trust for Ornithology (BTO), and The Buckinghamshire and Milton Keynes Records Centre to help devise a monitoring scheme for a National Lottery Heritage Fund Landscape Partnership project, based in the central Chilterns (The Chalk, Cherries, Chairs project[4]). This scheme is based on stratified (by habitat) random 1km$^2$ sample squares. Each sample square will be monitored using national scheme protocols for birds (BTO breeding bird survey), butterflies (BC Wider Countryside Butterfly Survey) and plants (Plantlife National Plant Monitoring Scheme). Results and further learning from this project will be shared with the wider conservation community.

[4] https://www.chilternsaonb.org/projects/CCC.html

BETTER
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps & recommendation | Synthesis & application

# Practical approach

## OP5.2 Comparative assessment of remote sensing sensors and application to quantifying habitat quality attributes

The project conducted a desk-based audit and research exercise into remote sensing approaches to quantifying habitat quality. Various remote sensing options were assessed to inform a suitable approach, to enable Kent Wildlife Trust to develop the expertise and capacity to deliver landscape-scale monitoring of habitat quality, and to provide a framework to enable others to develop suitable, practical, remote sensing approaches. Presented here are comparative assessments of the hardware, software, training and insurance requirements that informed the development of an approach to measuring habitat quantity using Unmanned Aerial Vehicle-based (UAV) remote sensing, and a case study of the approach developed.

| Sensor options | Description | Cost<br>£ = <1000<br>££ = 1001-5000<br>£££ = >5000+ | Strengths | Weaknesses | Habitat attributes | Examples | Suitability and application |
|---|---|---|---|---|---|---|---|
| Video | High-definition video, live stream to device and/or recording. | **£-£££** (basic to feature film quality cameras available) | • Can show where and what broad habitat types are.<br>• Useful for public engagement, marketing, fundraising, reporting to funders. | • Non-quantitative.<br>• Huge data storage requirement (but cloud storage and video compression can reduce costs). | • Habitat extent.<br>• Habitat type/ composition. | • A fly-over showing broad habitat types and their extent. | Suitable for a general impression of an area rather than quantitative assessment. |
| Visible Red Green Blue (RGB) Imagery (still) "True-colour" visual band photographs | High-resolution, low distortion aerial imagery, manual Aerial Photo Interpretation (API). | **£-££** | • Humans are capable of differentiating subtle differences in images.<br>• Cheap if use existing aerial photographs (more expensive to commission).<br>• Intuitive images, wide range of uses, humans can use clues in an image to help habitat identification (e.g. Friesian cows in a field indicate likely to be improved grassland).<br>• Use of images for wider purposes such as public engagement; marketing/fundraising; demonstrations to funders.<br>• Data collection can be carried out with low-cost UAV. | • Human API is time consuming.<br>• Manual digitising can be inaccurate.<br>• Humans can be inconsistent in categorising habitats.<br>• Some metrics can't be assessed (e.g. vegetation height) from API without a stereoscopic view. | • Habitat extent.<br>• Habitat type/ composition.<br>• Habitat structure. | • Mapping scrub cover, heather regrowth.<br>• Accurately mapping areas of similar contiguous habitat to be checked "ground-truthed" in the field for detailed ID. | Suitable for small areas for which repeat survey is not required frequently. |
| Visible Red Green Blue Imagery (still) "True colour" visual band photographs | High-resolution, low distortion aerial imagery, digital image processing | **£-££** | • Two prominent pixel-based options are 'supervised' (computer trained first by user selecting pixels representing specific habitat classes); or 'unsupervised' image processing (algorithm groups pixels with common characteristics).<br>• With high spatial resolution images, a superior method is 'object-based image analysis' (OBIA), which groups pixels into representative vector shapes with size and geometry based on shape, texture, spectral value and/or geographic context.<br>• Photogrammetry can also be used to create digital terrain and digital surface models (DTM and DSM) which enable habitat structure to be assessed.<br>• Data collection can be carried out with low-cost UA | • Can be relatively time-consuming training the algorithm and/or interpreting the results, although an increasingly large volume of open-source approaches are being released to calculate a variety of useful ecological outputs.<br>• High spatial resolution of data can lead to classification issues e.g. shadow classification or classification of non-distinct habitats.<br>• Object based classification performs better with multispectral data. | • Habitat extent.<br>• Habitat type/ composition.<br>• Habitat structure (photogrammetry). | • Mapping scrub cover, heather regrowth etc.<br>• Accurately mapping areas of similar contiguous habitat to be ground truth-ed in the field for detailed ID. | Suitable for small-medium areas, where repeat survey can be carried out. Other geospatial datasets can be included (e.g. topographic, hydrological) to increase detail of classification. |
| Multi-spectral Imagery (still): many spectral band combinations available. Includes bands beyond the human visual range. *Three specific types of multispectral imagery are described in the rows below.* | Typically based on relating spectral properties to the distribution of habitat, species or functional groups. Imaging spectroscopy can be used to assess biodiversity via plant traits or spectral information content. | **££-£££** | • *Spectral diversity:* emerging methods using spectral diversity (optical diversity) as a proxy for terrestrial plant diversity enable the study of diversity (phylogenetic, taxonomic, and functional) of plant communities.<br>• *Optical trait indicators:* a study found optical trait indicators out-performed canopy reflectance spectra as indicators of plant species composition and they were found to be easier to interpret in an ecological sense than spectral bands or features. The study concluded they have a high indicative value for ecological research and applications[7].<br>• *Derived spectral indices:* different band combinations provide a range of indices describing surface properties (e.g. Normalized Difference Vegetation Index - NDVI). | • The complex drivers of plant optical properties are not well understood.<br>• The scale dependence of spectral diversity – biodiversity relationship can confound diversity monitoring using remote sensing.<br>• Optical trait indicators are temporally variable, therefore data collection must be timed to take into account short-term/ seasonal vegetation dynamics.<br>• Need to be aware that optical trait indicators may vary at fine scales. | • Species composition.<br>• Habitat extent.<br>• Habitat type/ composition.<br>• Habitat structure (photogrammetry). | • Bands of multispectral data can be combined in various indices to measure surface properties (e.g. NDVI for measuring vegetation greenness)<br>• Vegetation dynamics and phenology.<br>• Biomass production.<br>• Land cover classification.<br>• Soil properties.<br>• Carbon sequestration.<br>• River and coastal habitat monitoring. | Suitable for small-medium areas, where repeat survey can be carried out. Other geospatial datasets can be included (e.g. topographic, hydrological) to increase detail of classification. |
| Multi-spectral Imagery a. Thermal | Tracks the relative surface temperature of land and objects | **££** | • Useful for research; monitoring animals (wildlife/livestock); search and rescue, plant crop health.<br>• Video from UAV can monitor animals as they move.<br>• Stills can look at stresses due to climatic/weather pressures, or heat plumes in water bodies. | • Huge data storage requirement for very high-resolution data. | • Habitat extent.<br>• Habitat management vector (wildlife/livestock) monitoring. | • Measuring plant foliage temperature to identify heat stress, water use, and plant metabolism.<br>• Soil salinity stress detection.<br>• Searching for/monitoring grazing livestock/wildlife. | Can be applicable to aquatic habitat quality where temperature affects quality/ habitability. |
| Multi-spectral Imagery b. Near Infrared and ultraviolet | Captures near-infrared radiation and ultraviolet light invisible to the human eye | **££-£££** | • Enables measurement of a range of properties of soils, water and vegetation.<br>• Can be combined into spectral indices for analysis of change. Vegetation indices can provide information on plant vigour, leaf area, and canopy cover to measure the health / growth / category of vegetation,<br>• Many different types available, suited to different climate, atmospheric and geographical conditions.<br>• Examples include:<br>• NDVI Normalized Differential Vegetation Index<br>• NDWI Normalized Difference Water Index<br>• SAVI Soil Adjusted Vegetation Index<br>• ARVI Atmospherically Resistant Vegetation Index<br>• EVI Enhanced Vegetation Index | • Huge data storage requirement for very high-resolution data.<br>• Complex cross-calibration procedures required for accurate historical trend analyses.<br>• Appropriate multispectral data management, sharing and use can be challenging. | • Habitat type/ composition.<br>• Habitat structure.<br>• Habitat extent. | • Examples:<br>• *Green Chlorophyll Index* (GCI) for monitoring the impact of seasonality, environmental stresses, pesticides effect on plant health.<br>• *Structure Insensitive Pigment Index (SIPI)* for monitoring plant health in regions with high variability in canopy structure or leaf area index, for early detection of plant disease or other causes of stress.<br>• IDB database for remote sensing indices provides an extensive list of derivable indices and a useful index search function *https://www.indexdatabase.de/* | The various indices built from multispectral band data can provide great metrics for measuring and monitoring habitat quality. Expensive data processing software often required. |
| Multi-spectral Imagery c. Hyperspectral | Captures spectral information to identify minerals, vegetation and other materials. | £££ | • Data gathered represents the entire spectrum of each pixel in a given image. | • Huge data storage requirement.<br>• Hyperspectral sensing is complex, requiring careful UAV flight planning.<br>• Application exceeds most conservation requirements. | • Habitat extent.<br>• Habitat type/ composition.<br>• Habitat structure. | • Enables measurement of plant health and identification of plant disease; Assessment of water quality; Performing precise vegetation index calculations; Determining mineral and surface composition; Fill spectral sensing; Conducting spectral index research. | Very precise vegetation monitoring, beyond the requirements of most conservation applications. |
| LiDAR (Light Detection and Ranging) | Collects high quality, accurate land and object surface elevation data. Topographic mapping/digital terrain and surface models (DTM and DSM). | £££ | • Can create digital terrain models of land and vegetation canopy surfaces.<br>• The denser the data, the greater flexibility in data analysis, mapping and modelling.<br>• Great detail captured, can use levels data to measure small changes e.g. erosion or restoration of peat. | • Huge data storage requirement.<br>• Although techniques are getting more automated, this is a very specialised area. Especially when using UAVs as a capture platform. | • Habitat extent.<br>• Habitat structure. | • Monitoring detailed elevation changes e.g. to show peat erosion/ restoration.<br>• Modelling water flow using bare earth topographic models.<br>• Evaluating drainage in fields.<br>• Surveying ground elevation changes along paths/routes.<br>• 3D modelling of structures such as buildings, bridges, and facades.<br>• Assessing soil excavation on construction sites.<br>• Vegetation structure, e.g. volume of timber at different height brackets in a woodland or estimating carbon storage of woody vegetation. | Suitable for a small to medium area for which frequent repeats are required. |

[7] *Feilhauer, H., Somers, B. & van der Linden, S. (2017) Optical trait indicators for remote sensing of plant species composition: Predictive power and seasonal variability. Ecological Indicators, 73, 825–833.*

# OP5.3 Comparative assessment of hardware and deployment solutions for UAV-based rote sensing [5]

## UAV hardware options

| Solution | Description NB The example UAV models given are not the only ones available in each group | Cost | Strengths | Weaknesses | Suitability and application |
|---|---|---|---|---|---|
| **Contractor** | Many specialist consultancies offer UAV services. | **£200+** depending on time/complexity involved. | • Training not required for flights or data processing.<br>• No staff time on flights and data processing.<br>• No purchases of hardware, training, insurance or data processing costs. | • May not fully be in control of flight timing, depending on consultant availability. | • Useful if you don't have many sites to study, can't train your own staff and/or can resource repeat surveys. |
| **'Out-of-the-box' UAV solution** | UAV with standard camera.<br><br>Examples:<br>• DJI Phantom 4<br>• DJI Mavic 2 Pro<br>• DJI Mavic 2 Pro Zoom<br>• Autel EVO II Pro<br>• Parrot ANAFI Extended<br>• DJI Mavic Air | **£100 - £5000** Camera quality will affect price. Real-Time Kinematic (RTK) ability or a thermal camera may push them out of this price bracket. | • Relatively simple to use.<br>• Can be deployed in-house.<br>• Gathers acceptable aerial photos and can produce digital surface and terrain models.<br>• Once UAV purchased and staff trained the only cost is staff time & any data processing fees.<br>• NB It is possible to be trained and take test with a cheaper, simpler UAV then later add a more complex one to your operations manual as long as in the same category (see **Table 5.5**). | • Lacks flexibility to mount additional hardware/ sensors.<br>• Training required, time & money. | • Useful if you have many sites to survey so worth training your own staff and if the custom sensors provide what you need. |
| **UAV with flexible sensor attachment options** | UAV with the option to attach a variety of sensors.<br><br>Examples:<br>• DJI Matrice 210 v2<br>• Skydio 2<br>• 3D Robotics Y6<br>• 3D Robotics Solo<br>• Draganflyer X6 | **£5000 - £16,000** | • Can be deployed in-house.<br>• Flexibility: a range of and multiple sensors can be mounted so can choose sensors to exactly match your requirements: multispectral, thermal etc.<br>• Flexible payload mounting positions above and below.<br>• Once UAV purchased and staff trained the only costs are staff time, insurance and data processing and storage fees. | • Need to know what sensors needed up front in order to choose UAV capable of carrying them.<br>• Training required, time and money.<br>• Large expense up front. | • Useful for if you have many sites to survey so worth training your own staff and have complex survey requirements as sensors can be fitted to suit. |

[5] *This table was informative by Duffy, J.P., Anderson, K., Shapiro, A.C., Spina Avino, F. L. DeBell & Glover-Kapfer, P. 2020. Drone Technologies for Conservation. WWF Conservation Technology Series 1(5). WWF.*



BETTER
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps & recommendation | Synthesis & application

## UAV category options

| Category of UAV | Strengths | Weaknesses | Suitability | Limitations |
|---|---|---|---|---|
| **Multi-rotor** | • More versatile & practical than fixed wing, can operate in confined space.<br>• Small take off space required.<br>• Vertical take-off and land (VTOL).<br>• Agile flight.<br>• Ability to hover.<br>• Often cheaper than fixed wing.<br>• Accessibility.<br>• Ease of use.<br>• Good camera control | • Limited endurance and speed permits less extensive coverage than fixed wing.<br>• Small payload capacity. | • Useful where agility, flexibility and a variety of image collection options required.<br>• Typical use: Aerial Photography and Video Aerial Inspection. | • Batteries: a primary limitation on duration of use is battery life. You may need many UAV batteries for a day's field work plus tablet and controller batteries.<br>• Weather: heavier, often more expensive, UAVs can fly in higher winds than others, but all UAV use is limited by inclement weather.<br>• Data storage: large volumes of data are generated, plan storage options ahead. Well organised data management, cloud storage, video compression and a couple of large (~£200) external disk drives will help. |
| **Fixed wing** | • Long endurance.<br>• Can cover larger areas than rotor UAV.<br>• Fast flight speed. | • Limited to areas with clear take off; can only take mapping images, not videos or other photos.<br>• Inability to hover.<br>• More expensive than rotor.<br>• Technically more challenging to operate than multi-rotor.<br>• Image processing more complex.<br>• Can be attacked by large birds of prey. | • Useful in large open areas for example arable monitoring many landscape-scale applications where agility is not required.<br>• Typical use: Aerial Mapping, Pipeline and Power line inspection. | |
| **Single-Rotor** | • VTOL and hover flight.<br>• Long endurance (with gas power).<br>• Heavy payload capability. | • More dangerous than multi-rotor or fixed wing.<br>• Technically more challenging to operate than multi-rotor or fixed wing.<br>• More training needed.<br>• Expensive. | • Unlikely to be preferred option for landscape-scale monitoring.<br>• Typical use: Aerial LIDAR. | |
| **Fixed-Wing Hybrid** | • VTOL.<br>• Long-endurance flight. | • Not perfect at either hovering or forward flight.<br>• Still in development. | • Development does not yet support widespread use, unlikely to be preferred option for landscape scale monitoring. | |

BETTER
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps & recommendation | Synthesis & application

# OP5.4 Comparative assessment of software options for image processing

| Solution | Cost<br>£ = 0-100<br>££ = 101-1000<br>£££ = 1001 + | Strengths | Weaknesses | Suitability | Website |
|---|---|---|---|---|---|
| **Pix4dmapper** | £££ | • Excellent for orthomosaics.<br>• Range of outputs provided in standardised formats.<br>• Wide range of support and online learning materials available.<br>• Dedicated free companion app. ('Pix4dcapture') excellent for flight planning and undertaking flights.<br>• Relatively straightforward to use, minimal input user interface.<br>• Very good at processing.<br>• Possible to buy one-month licence more cheaply which is useful if you can save up all your data processing. | • High cost for processing.<br>• Less control over outputs than Agisoft Metashape (no internal Python support).<br>• Support & updates for one year only on perpetual license.<br>• Extensions for added functionality start from at least 10% of license price.<br>• Potential compatibility issues in future without extensions. | • Very capable but too expensive for most processing.<br>• Free companion app useful for flight planning.<br>• Suitable for organisations with sufficient funding but likely too expensive for the majority of conservation organisations. | pix4d.com |
| **Agisoft Metashape** | £££<br>*(professional edition)*<br>££<br>*(standard edition)* | • Best for 3D modelling.<br>• Affordable cost of Standard Edition ($179 for one license) – can produce 3D models at a lower cost than other options, but analysis and orthomosaic options seem limited.<br>• Internal Python support allows greater control over outputs.<br>• More powerful than Pix4D, allows programmatic control through a Python interface but also has a very usable graphical user interface (with a few quirks).<br>• 1 month trial with full functionality available. | • High cost of professional edition.<br>• Steeper learning curve the other paid for solutions.<br>• No dedicated companion app. available.<br>• May not include all of the analysis options required. | • Can deal well with multispectral sensor's TIF images.<br>• May not provide all required functionality.<br>• Suitable for organisations with sufficient funding but likely too expensive for the majority of conservation organisations. | agisoft.com |
| **Drone Deploy** | ££ | • Range of outputs provided in standardised formats.<br>• Wide range of support and online learning materials available.<br>• Dedicated desktop and linked mobile companion app ('Live Map') for planning flights, allows import of shapefile/KML data.<br>• Cloud-based rendering reduces hardware requirements and enables collaborative working. | • High cost.<br>• Cloud-based rendering is dependent on remote servers.<br>• Cloud-based, may be data privacy issues. | • Suitable for organisations with sufficient funding but likely too expensive for the majority of conservation organisations. | dronedeploy.com |
| **WebODM** | £ | • Open source (with one-off install fee, although can be installed for free through docker with some technical skills)<br>• Huge cost savings over alternative software.<br>• Cloud based rendering not essential but available if needed at a relatively low additional cost.<br>• Output from 'Pix4dcapture' app seems to be compatible.<br>• Open-source software increases potential for additional functionalities to be added.<br>• Developer released R and Python packages to analyse resulting data and create various models (NDVI, NGRDI, etc.) as well as remove soil, count objects, estimate canopy cover, etc. | • Less support available.<br>• Software bugs more likely and may take longer to correct than paid alternatives.<br>• Steep learning curve with little guidance documentation.<br>• Time investment in learning the software.<br>• Output quality more heavily dependent on the skill of the software user.<br>• Lack of guaranteed future development of software. | • Low cost and rich in features.<br>• Needs time and technical knowledge to use.<br>• Suitable for organisations with high technical skills. | hopendronemap.org/webodm/ |
| **Precision Analytics** | £££ | • Good quality software.<br>• Automated crop counting and sizing, on-demand vegetative indices, and flexible zonal statistics. | • High cost now (previously more affordable). | • Suitable for organisations with sufficient funding but likely too expensive for the majority of conservation organisations. | precisionhawk.com/software |
| **Maps Made Easy** | Free - £ | • Free for smaller projects.<br>• Very useful for data processing.<br>• Can split up larger projects into free ones or use pay as you go processing.<br>• Can pay for faster processing if required.<br>• Makes orthomosaics, digital elevation models, point clouds & 3D models. | • Limitations on free data processing (number of images).<br>• Cannot deal with TIFs, only JPEG images.<br>• The data processed is automatically viewable publicly on the website.<br>• Can only process a small number of images for free, and combining images does not result in seamless boundaries. | • Very useful for free or low cost data processing of JPEG data for small areas, or larger surveys which can be split up.<br>• Can't deal with multispectral sensor's TIF images.<br>• Suitable for small projects with limited technical experience. | mapsmadeeasy.com |
| **ArcGIS Drone2Map** | £ | • Well made, reputable software.<br>• Very fast processing, results can be processed and viewed in the field to check coverage and quality before you leave site.<br>• Produces both 2D and 3D products for analysis and visualization.<br>• Ground control point data gathered using ESRI Collector app can be integrated. | • Annual licence fee.<br>• Also requires ArcGIS (at least Online) licence in addition (but this is only ~£110+VAT a year for charities). | • Requires prior knowledge of ArcGIS.<br>• Suitable for organisations with sufficient funding and an existing Arc licence, but likely too expensive for the majority of conservation organisations. | esriuk.com/en-gb/arcgis/products/drone2map/overview |
| **Virtual SFM** | £ | • 3D reconstruction using structure from motion | • Only handles JPEG images.<br>• May not handle radiometric calibration of images. | • Free but limited functionality. | ccwu.me/vsfm/ |

**Data Output options**
- Orthomosaic - geo-located images tiled into one coverage.
- 3D model - triangulated from overlapping images.
- Point Cloud - set of data points in 3D space.
- Digital Surface/Terrain - digital map of the elevation of an area.

## OP5.5 Comparative assessment of UAV pilot training options

| Training requirement | Description | Cost | Strengths | Weaknesses | Comments on suitability |
|---|---|---|---|---|---|
| *General Visual line of sight Certificate ('GVC')* | Fully online course no support with just flight test in person. | **£300-800** | • Most affordable.<br>• Can be fitted around other commitments, flight practice etc. | • No/few opportunities to clarify queries.<br>• Risk of misunderstanding.<br>• No hands-on flight training. | Useful if budget limited. |
| | Theory tuition online with remote support available and one taught day with instructor to answer queries, theory test online, flight introduction day with instructor, test in person. | **£700-£1000** | • Ability to clarify any queries as needed.<br>• Can be fitted around other commitments, flight practice etc.<br>• Mix of flexible online training which can be fitted around other work, with in person (online) support available when needed. | • Limited hands-on flight training. | Affordable, flexible option. |
| | In person course with test on completion. | **£1000+** | • Able to clarify queries in person in real time.<br>• May provide templates for the required operations manual[9], and for the various flight, battery, equipment etc. logs which have to be maintained. | • Often requires additional budget for travel and accommodation for several days.<br>• Need to find a course at a time to suit your schedule.<br>• Need to be an experienced pilot already in order to take practical test straight after course. | Most hands-on, greatest teaching contact time. |

[9] *One of the most important stages of drone training. The Operations Manual (OM) is a document that explains to the CAA how you will conduct yourself when you are operating a drone. Includes detail on safety training, nominated personnel, aircraft systems, incident reporting, flight planning, procedures and emergencies, necessary documentation needed for operations, information about the operations you will be undertaking, the aircraft you will be flying and the pilots operating under the auspices of the OM.*





## OP5.6 Comparative assessment of UAV insurance options

| Insurance option | Cost* | Strengths | Weaknesses | Suitability |
|---|---|---|---|---|
| Pay-as-you-fly (flight only cover) with personal/public liability only (rather likae third party car insurance). | £ | • Meets legal requirement for cover for damage to people and property.<br>• Useful if UAV use infrequent. | • Damage to UAV not covered.<br>• Administrative burden of arranging cover for each flight operation. | • Useful for occasional use of low value equipment. |
| Pay-as-you-fly (flight only cover) including personal/ public liability and cover for kit damage while flying. | ££ | • Meets legal requirement for cover for damage to other people and property.<br>• Damage to UAV covered.<br>• Useful if UAV use infrequent. | • Administrative burden of arranging cover for each flight operation. | • Useful for occasional use of low value equipment. |
| Annual policy for e cover with limited number of flights included (personal/ public liability and kit damage). | ££ | • Meets legal requirement for cover for damage to other people and property.<br>• Damage to UAV covered.<br>• Convenient, time saved arranging flight cover each time you are out. | • Need to keep track of your flight operations. | • Useful for occasional use where administrative burden is inconvenient. |
| Annual policy for kit cover including unlimited flight cover (personal/public liability and kit damage). | £££ | • Meets legal requirement for cover for damage to other people and property.<br>• Damage to UAV covered.<br>• Convenient, reduced administrative burden. | • Upfront expense. | • Useful for regular use where administrative burden is inconvenient. |

** Indicative only as many variables affect the cost e.g., UAV value, flight time, pilot training and majorly, and level of public liability cover required.*


Bare groud, understory and canopy; strutctural attributes of habitat quality © Neil Aldridge

# OP5.7 Case study – West Blean and Thornden Woods: digital surface modelling to assess structural attributes of habitat condition.

## Survey design

The project sought to develop a practical remote sensing approach to quantify structural attributes of habitat quality within a study landscape. Development was informed by the steps defined in **Chapter 3.**

| 1. Define landscape parameters | 2. Define theme to be addressed | 3. Articulate objective, question or hypothesis | 4. Specify required data | 5. Attributes of monitoring programme | 6. Selecting indicator(s) | 7. Develop practical approach |
|---|---|---|---|---|---|---|

**1. Define landscape parameters:** the parameters of the study landscape were defined as the entire extent of Kent Wildlife Trust's landholding within West Blean and Thornden Woods SSSI, an area of approximately 500 ha.

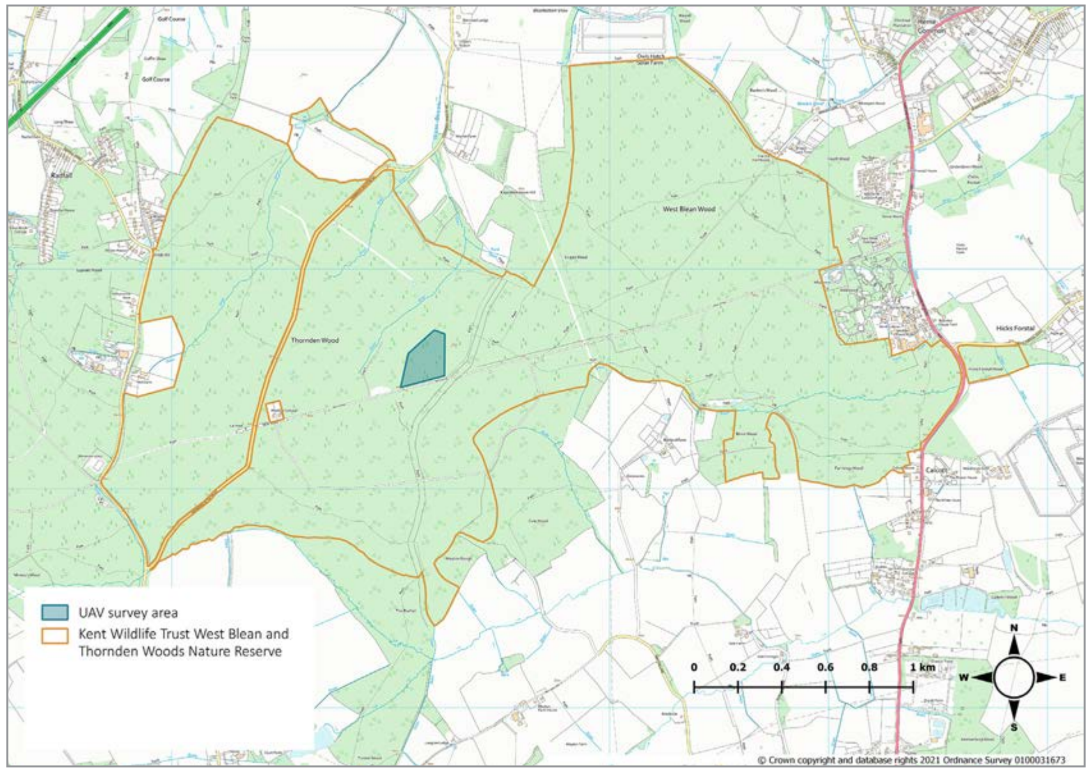



*Figure 5.1* **UAV sample location West Blean and Thornden Woods SSSI, near Canterbury, UK. © Ordinance Survey.**

**2. Define theme to be addressed:** structural attributes of habitat quality.

**3. Articulating the objective, question or hypothesis:** in the immediate term the objective was simply to attempt to quantify the structural variation of vegetation within the study site. In the longer term, the hypotheses are:

- H0: there is no evidence of change in the structural variation of vegetation within the study landscape.
- H1: there is evidence of change in the structural variation of vegetation within the study landscape.

As remote sensing approaches to assessing habitat quality are developed, we anticipate a need to establish common metrics and assessment criteria against which habitat quality can be assessed. These will inform more specific hypotheses going forward.

### 4. Attributes of monitoring programmes

Survey design was informed by the attributes from *OP3.3* **Ordered list of attributes of monitoring programmes**. This output presents a ranking of attributes of monitoring programmes in order from most elemental to most aspirational. The table below details how the survey design considered and adopted these attributes.





| Attribute | | Comment |
|---|---|---|
| Most elemental | Objectives and questions defined | From the outset the objective was articulated. |
| | Standardised methods and protocols | Standard methods and protocols for operational aspects of UAV-based survey are available and were adopted. For the application of techniques to the assessment of habitat quality these are not well established. The next steps and recommendations section of this chapter signposts work to progress their development. |
| | Suitable, accurate, efficient sampling methods | The sensor used provided suitable, accurate, efficient sampling methods for the intended purpose. |
| | Sufficient contributors | The training and deployment of two personal was sufficient for the intended survey. |
| | Suitable and accessible identification resources | Not applicable. |
| | National, regional, or local coordination | To our knowledge, there is no national, regional, or local coordination of the gathering and application of remote sensing data to conservation applications. |
| | Efficient data entry, storage and processing systems | Use of the available and appropriate software applications provided efficient data management systems. |
| | Data is reliable and validated | To our knowledge, there is no procedure for the validation of remote sensed data. |
| | Results and findings fed back to participants | Not applicable. |
| | Sufficient contribution of specialist knowledge | Relevant personnel underwent training to acquire the specialist knowledge required to conduct the survey. |
| | Appropriate analytical approaches available | While statistical analysis was outside the remit of this survey (as no repeat survey with which to make comparison has yet been conducted) appropriate techniques are well established. |
| | Good retention of contributors | Contributors were employed by Kent Wildlife Trust and retained through contract of employment. |
| | Mentoring, training and support for contributors | Training in the relevant UAV techniques is widely available. We recognise a need to establish programmes of training, mentoring and support for the application of remote sensing in conservation practice. |
| | Analytical and statistical approaches accessible | At the time of writing approaches were out of scope of our organisation, however Kent Wildlife Trust is now taking steps to recruit personnel with the relevant skill sets. |
| | Change reported at appropriate intervals | A plan to report change at appropriate intervals is embedded in the relevant organisation monitoring programme. |
| | Appropriate, scientific, sampling design | The design for the survey was designed to achieve completed coverage of the study landscape (though full coverage was out of scope within the project timeframe). |
| | Simple reporting of widespread and common species/attributes available to all | Spatially referenced maps allowing visual interpretation and accessible assimilation of the data were produced. |
| | Results disseminated widely | A plan to disseminate results to all relevant stakeholders is embedded in the relevant organisation monitoring programme. |
| | Best practice shared between organisations and schemes | Best practice is beginning to be developed and shared, though the is a need for more comprehensive and consolidated guidance on the practical application of remote sensing by practitioners. |
| | Indicator/important species or attributes identified | Not applicable. |
| | Wide coverage by participants | The survey was designed at landscape-scale. |
| | Collection of supplementary data (i.e. habitat soil, weather) | Not applicable. |
| | Focus on important species, locations, habitats etc. | The chosen species indicator taxa are both priority species for Kent and are included in the Kent Biodiversity Strategy. The chalk grassland habitat is also of national importance and a priority habitat for Kent. |
| | Electronic data capture | Data capture using a UAV and sensors is inherently electronic. |
| Most aspirational | Change reported annually | Annual reporting cycles for habitat change are not considered essential in this instance, where habitat changes are likely to operate over greater than annual intervals. |

**5. Selecting indicator species(s)**
Not applicable.

**6. Practical approach:**

**a)** Kent Wildlife Trust purchased a DJI Matrice 210 v2 UAV[6] with camera and MicaSense RedEdge MX multispectral sensor[7]. The Matrice was chosen as it allowed a degree of flexibility and future proofing. Rather than being restricted to use of an integral sensor only, aftermarket sensors can be fitted, and it can also carry a payload above as well as below the unit, which many UAVs cannot. A sensor mounted above can view directly upwards. This can be useful where an upward view is required, i.e. for surveying a tree canopy overhanging a water course. Sensor requirements included a visual camera capable of producing good quality still images to allow use for marketing as well as monitoring purposes in future. We also required a multispectral sensor to enable creation of vegetation indices for habitat condition monitoring. There are two market leaders, the MicaSense RedEdge MX and the Parrot Sequoia multispectral sensors. A table comparing their features is provided below. The RedEdge was chosen for its greater functionality and therefore better futureproofing to maximise application as organisational knowledge and demands increase.

**Comparison of market leading multispectral sensors.**

| Feature | MicaSense RedEdge MX | Parrot Sequoia |
|---|---|---|
| **Sensor** | • More powerful, captures five discrete spectral bands, allowing creation of many tailored indices.<br>• No visible red green blue (RGB) image sensor ('ordinary' camera) included, but can create composite RGB images:<br>• Blue (475 nm centre, 20 nm bandwidth)<br>• Green (560 nm centre, 20 nm bandwidth)<br>• Red (668 nm centre, 10 nm bandwidth)<br>• Red edge (717 nm centre, 10 nm bandwidth)<br>• Near-IR (840 nm centre, 40 nm bandwidth). | • Four narrowband filters which are optimised for analysing crop health.<br>• Sunshine sensor records the intensity of light emanating from the sun in these four same bands of light.<br>• Includes 16megapixel visible RGB images.<br>• Blue (475 nm centre, 40nm bandwidth)<br>• Green (550nm centre, 40 nm bandwidth)<br>• Red (660 nm centre, 40 nm bandwidth)<br>• Red edge (735nm centre, 10 nm bandwidth)<br>• Near-IR (790nm centre, 40 nm bandwidth). |
| **Sensor size/weight** | • 9.4 cm x 6.3 cm x 4.6 cm and 173g. | • 59mm x 41mm x 28mm and 72g. (Can be carried by a smaller UAV than the RedEdge) |
| **Image quality** | • High quality orthomosaic produced from the images.<br>• Can cope with fast speeds and low altitudes.<br>• Little distortion, as a global shutter design means images are captured adeptly. | • Plastic lenses create less sharp images.<br>• Slightly convex lenses so cover more ground in one view but this makes processed images less accurate and some software crashes have been reported when image processing. |
| **Flexibility** | • Compatible with a number of UAV platforms means serial, ethernet and Pulse Width Modulated (PWM) / General Purpose Input Output (GPIO) trigger are all possible.<br>• Standard features of geo-tagging and time stamping.<br>• Extra self-triggering function and external GPS connections available so no need to connect to host vehicle. | • GPS, Inertial Measurement Unit (IMU), magnetometer and SD card slot. |

**b)** Two staff were trained in Permission for Commercial Operations (PfCO) and General Visual Line of Sight Certificate (GVC) qualifications.

**c)** A sample area of West Blean and Thornden Woods was flown in November 2020, gathering overlapping aerial photos and multispectral images. We imported a KML file of the area of the survey onto the Matrice's controller and used DJI Pilot to plot the route, setting the flying height at 100m and an image overlap of 85% forward and to the side.

**d)** A number of models and indices were created from the data as examples of the information that could be created from the data gathered.

[6] https://flyingdrones.co.uk/matrice-210-v2-2/
[7] https://www.sensefly.com/camera/rededge-mx-multispectral-camera/





**Models and indices derived from UAV survey data.**

| Model/Index | Figure | Source | Description | Application to assessment of habitat condition |
|---|---|---|---|---|
| **Orthomosaic (a)** | 5.2 | Aerial photos | WebODM was used to produce an orthomosaic of the aerial photograph (true colour) .jpeg files. | This allows visual comparison of change over time and either manual aerial photo interpretation or digital categorisation into different habitat types. |
| **Digital Elevation Model (DEM)** | 5.3a and 5.3b | Aerial photos | WebODM was used to produce a Digital Surface and Terrain Model from the orthomosaic. | Provides a map of the habitat structure, from the relative heights of the vegetation over the image, not as accurate as LiDAR but satisfactory for most conservation purposes. |
| **Orthomosaic (b)** | 5.4 | RedEdge MX multispectral .tif images | This enabled the generation of various indices. | Vegetation indices were derived from this orthomosaic. |
| **Green Normalised Difference Vegetation Index (GNDVI)** | 5.5 | Orthomosaic (b) | Has wider dynamic range than NDVI and is, on average, at least five times more sensitive to chlorophyll-a concentration. GNDVI is used to detect the concentration of chlorophyll, to measure the rate of photosynthesis, and to monitor plant stress. It is calculated from (NIR–GREEN) / (NIR + GREEN) i.e. (band 5 – band 2) / (band 5 + band 2). | GNDVI is an index used to estimate photo synthetic activity and is commonly applied to determine water and nitrogen uptake into the plant canopy. |

Going forward, images will be collected using a standardised procedure, improving comparability between images acquired at different times and locations. This approach will be used to create a baseline dataset for the whole of West Blean and Thornden Woods, repeated regularly to monitor structural and vegetation changes, using appropriate indices, in response to management interventions. Only some of the above models are demonstrated below, but each have specific uses that would be explored in order to assess plant structure, health and activity throughout the monitoring process.


Lady orchids in a botanically rich woodland glade.

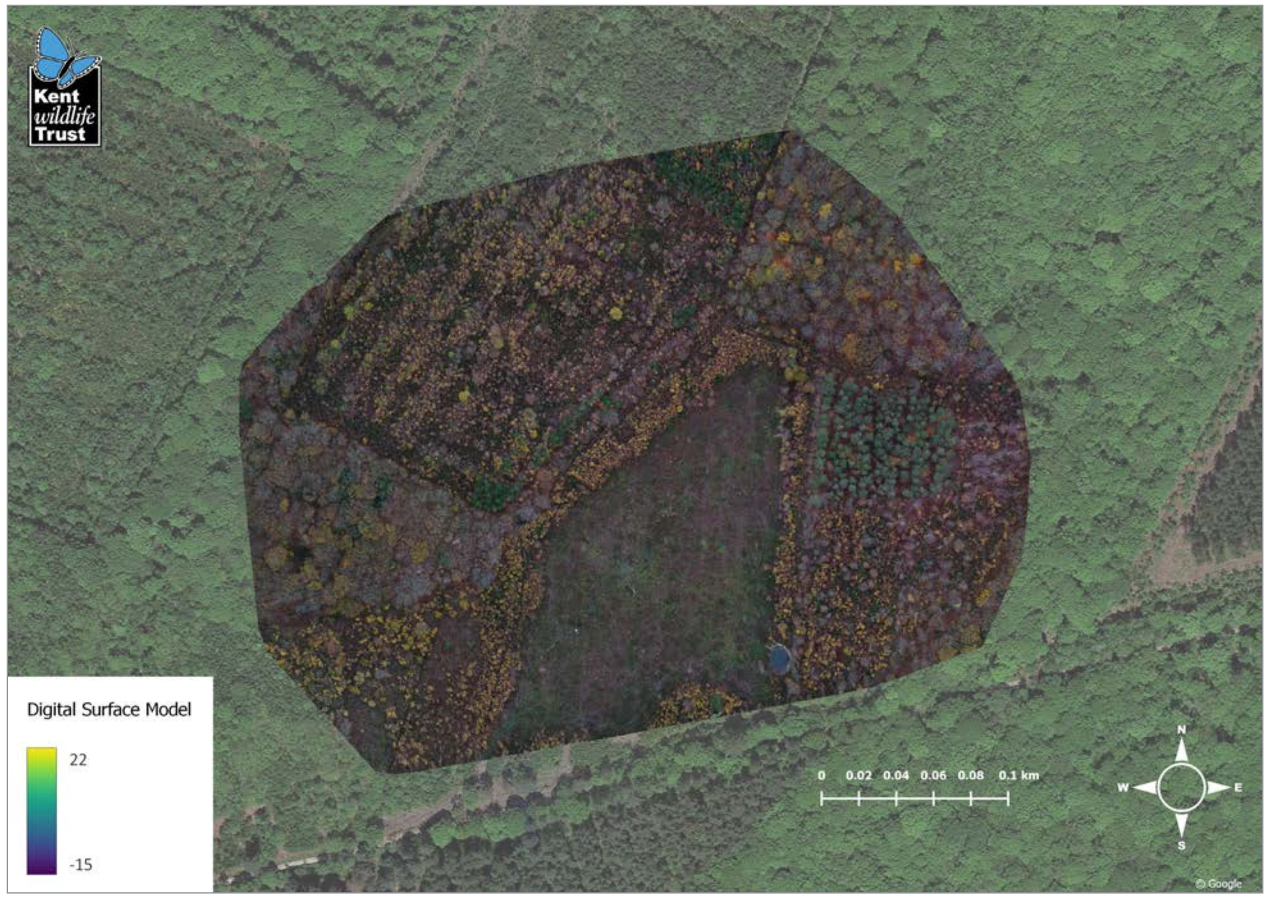



*Figure 5.2* **Orthomosaic of aerial imagery overlain on a satellite image base map, West Blean Woods, Canterbury, Kent.** Image shows a grassland clearing bordered by woodland, with a pond to the south-east.

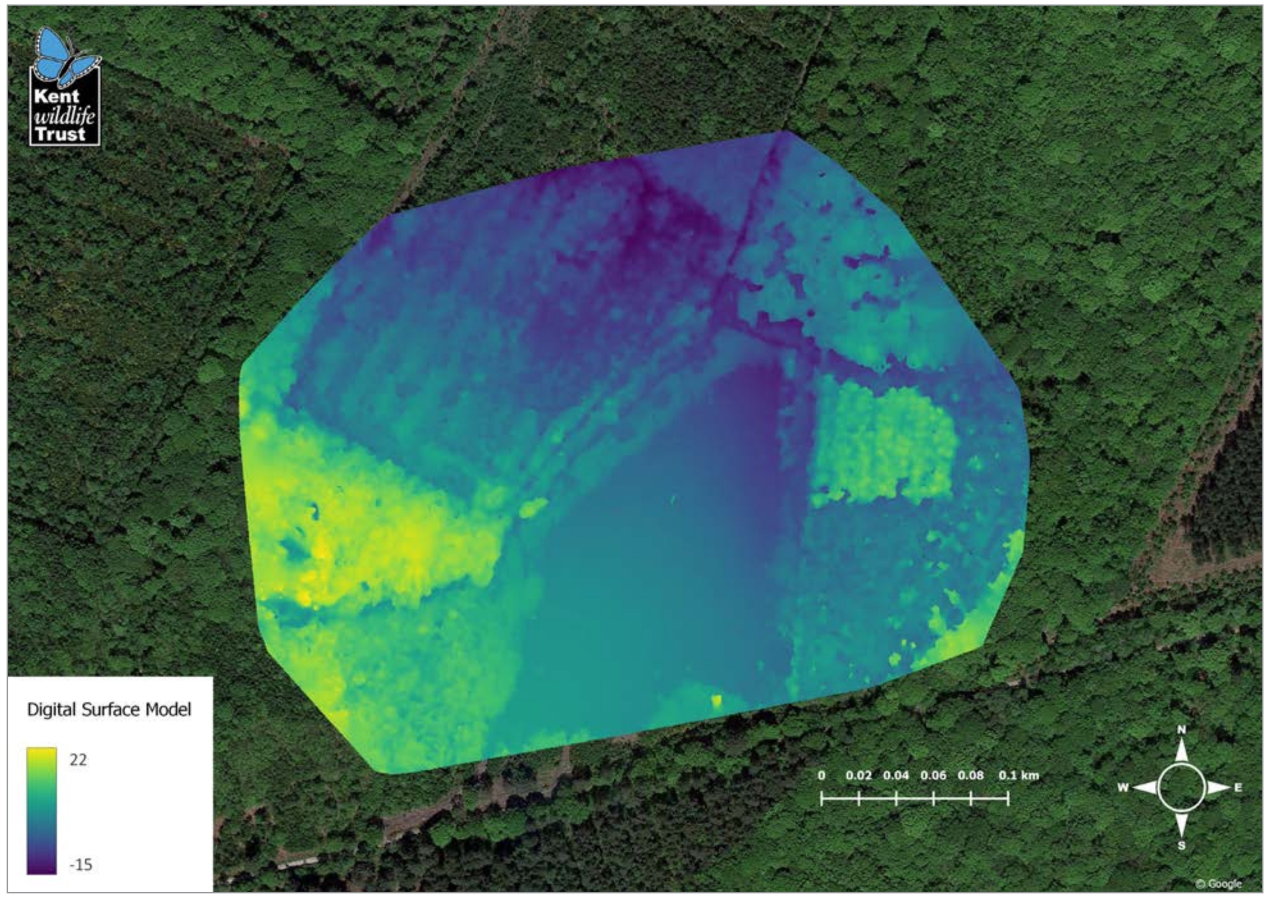



*Figure 5.3a* **Digital Surface Model created using OpenDroneMap, showing the heights of the vegetation relative to the take off point, West Blean Woods, Canterbury, Kent.**



BETTER
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps & recommendation | Synthesis & application

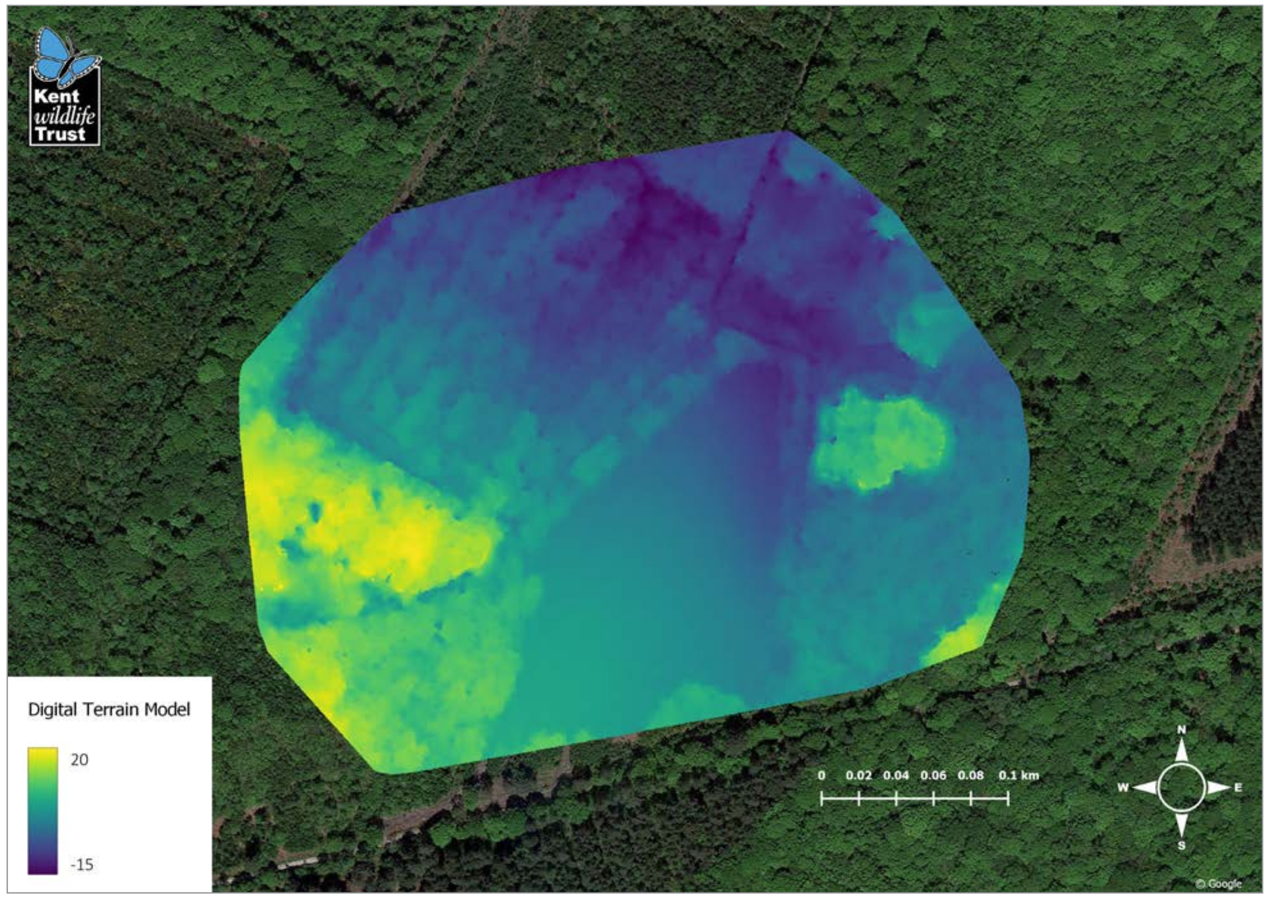



*Figure 5.3b* **Digital Terrain Model created in OpenDroneMap, showing the terrain elevation relative to the take off point, West Blean Woods, Canterbury, Kent.**

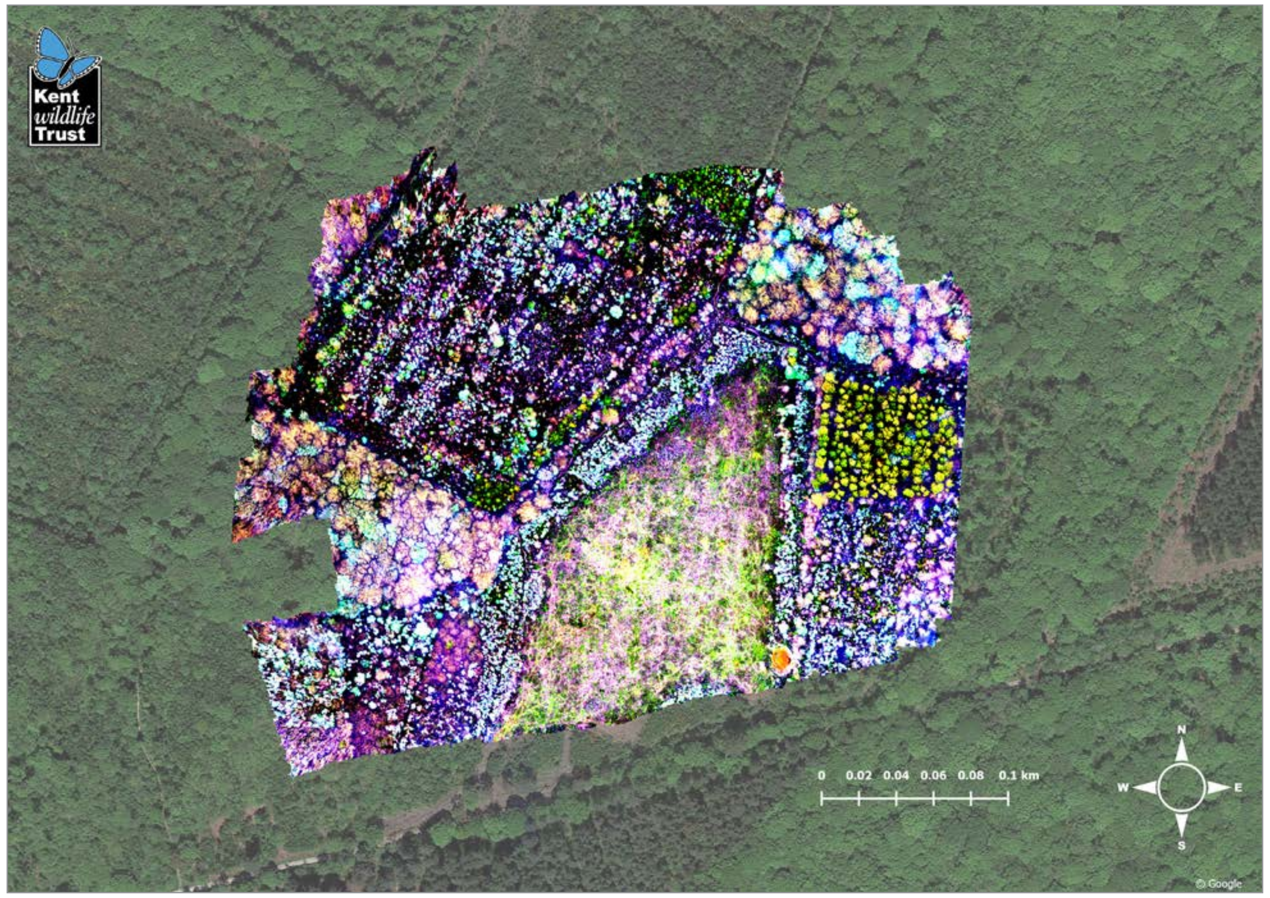



*Figure 5.4* **Normalised multispectral orthomosaic (of a sample of images overlapping but reaching further north than in figures 2, 3a and 3b) created in Agisoft Metashape, West Blean Woods, Canterbury, Kent.** Note: a legend was unavailable for this file format.

Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

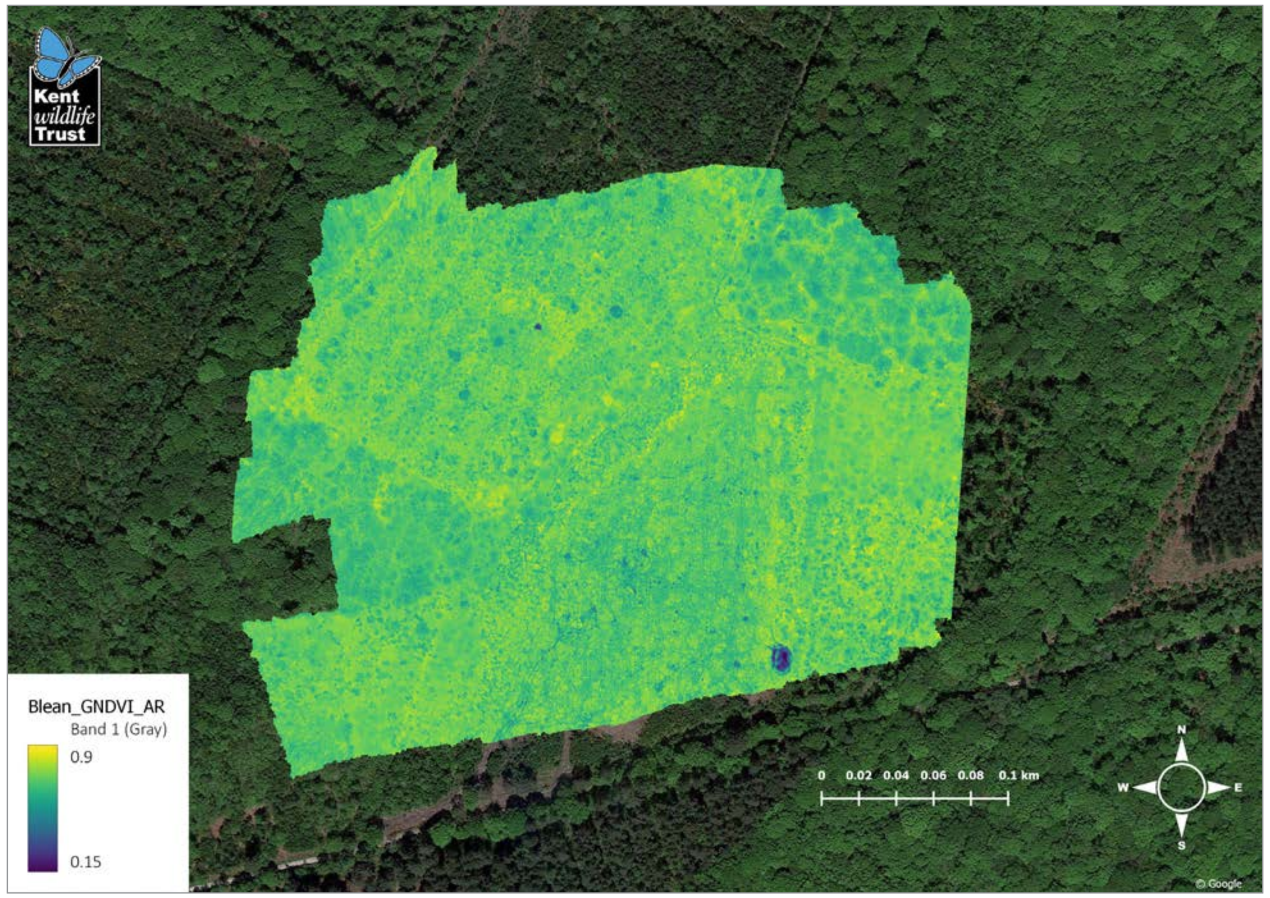



*Figure 5.5* **Green Normalised Difference Vegetation Index (GNDVI), West Blean Woods, Canterbury, Kent.**

## Measuring vegetation structure

Monitoring habitat quality requires quantitative data, and it is possible to derive this from the aerial images. A key attribute of habitat quality is the structure and variation in vegetation, for example the variation in size of trees in different size classes. A common woodland management objective is to increase structural variation (i.e. the variety of sizes classes of trees) and promote natural regeneration, which can be quantified by monitoring abundance and canopy area of trees within size classes, assessing change against baseline data. Due to computational restraints, a sub-sample of the aerial imagery was selected for analysis to demonstrate how this will be achieved for the whole site (**Figure 5.6**).

Using the orthomosiac raster outlined in **Figure 5.2**, and the R package 'FIELDimageR' [8] developed by OpenDroneMap, each individual object, in this case tree, was identified and its area calculated. This resulted in the vegetation structure detailed in Figure 5.7. This shows that the smallest trees measured by width, have the greatest variation in canopy area, and are most abundant. The largest trees have far less variation in canopy area and they are the least abundant size class. Repeat survey and analysis will demonstrate any change in the abundance of trees in each size class, and any change in canopy area, allowing a structural variation component of woodland habitat quality to be monitored.

An alternative way of visualising the data is a waffle chart (**Figure 5.8**). This offers an engaging way of presenting complex data to non-specialist audiences and may be useful for communication change in habitat quality to the general public, for instance through social media, as it is eye catching and displays the data in less detail.

Further analysis will allow the variation in abundance of trees within height classes to be quantified and monitored through the use of Digital Terrain and Surface Models.



[8] https://github.com/OpenDroneMap/FIELDimageR






*Figure 5.6* **Sub-sample of aerial imagery selected for vegetation structure analysis.**
Sub-sample indicated by pink grid

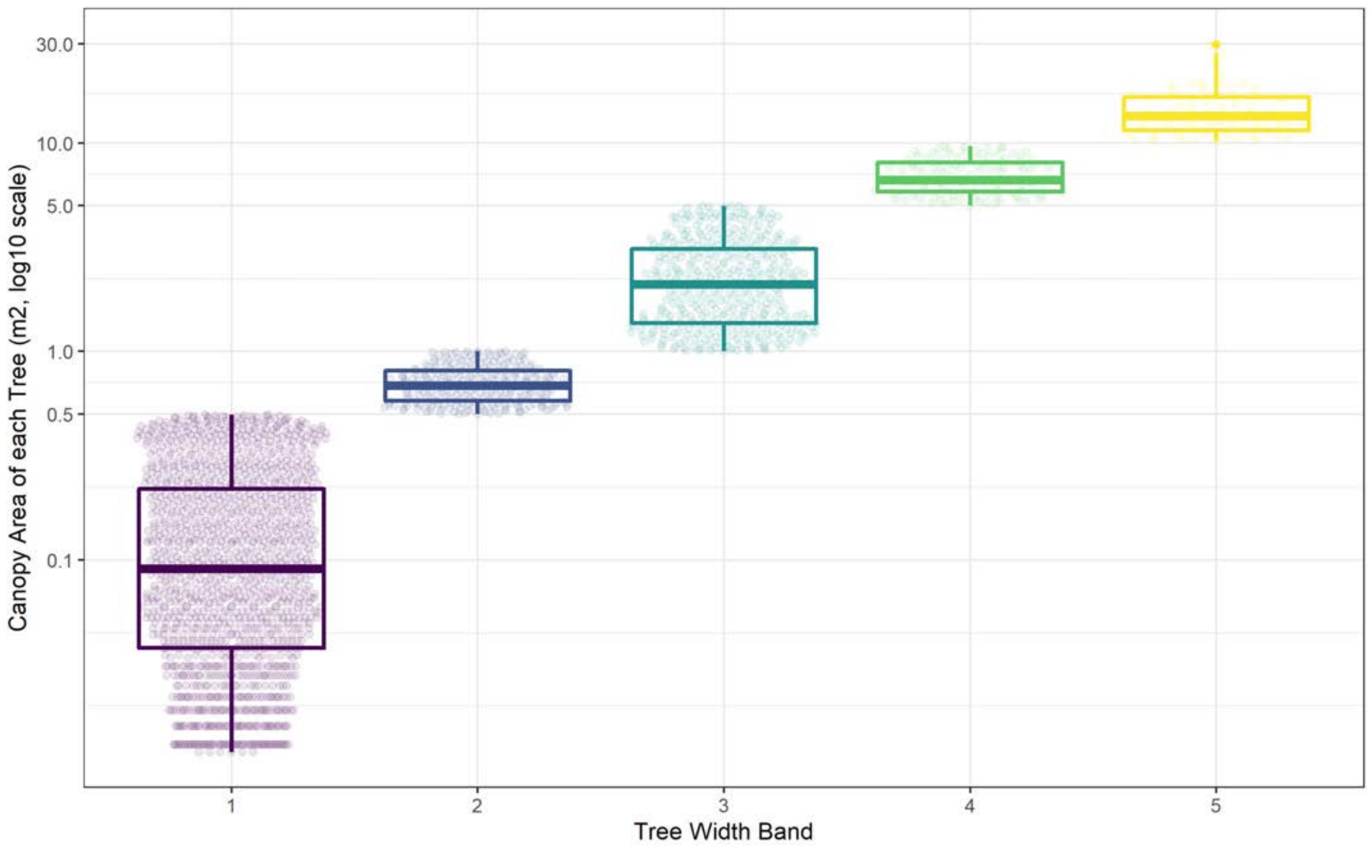



*Figure 5.7* **Boxplot showing tree areas in a sub-sample of aerial imagery from West Blean and Thornden Woods, in each of five width bands, (1 = 0-0.5 m², 2 = 0.5-1 m², 3 = 1-5 m², 4 = 5-10 m², 5 = >10 m²).** The vertical lines show the full range of tree areas in each class and extend to the smallest and largest areas. Boxes show the interquartile range with the median shown as a bold line. Whiskers extend to the smallest and largest observations or 1.5 times the interquartile range, whichever is smaller with outliers shown by filled circles. Points show raw data, arranged in a "beeswarm" plot, which plots points of the same value adjacent to each other, allowing both distribution and frequency to be visualised.

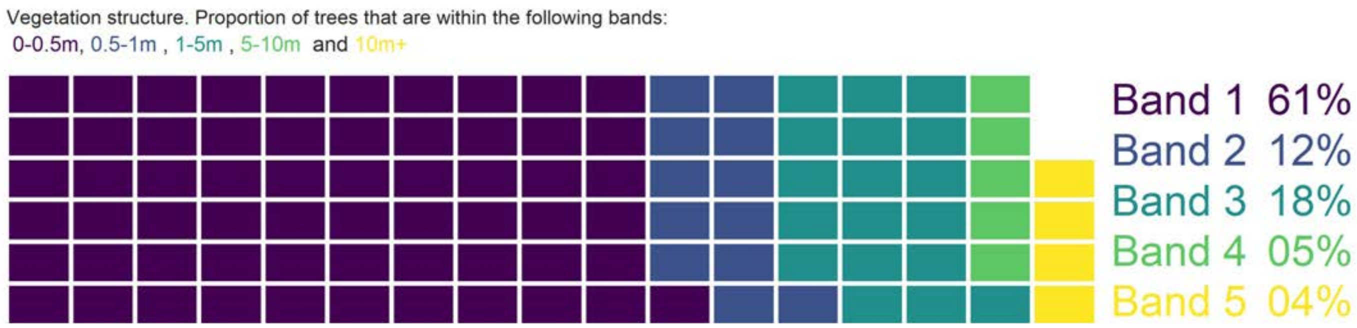



*Figure 5.8* **Waffle chart showing the proportion of trees in a sub-sample of aerial imagery from West Blean and Thornden Woods, in each of five width bands, (1 = 0-0.5 m², 2 = 0.5-1 m², 3 = 1-5 m², 4 = 5-10 m², 5 = >10 m²)**





# Limitations

The COVID-19 pandemic and the three subsequent government-sanctioned lockdowns within the timeframe of the project restricted progress with staff training, qualification, surveys and data analysis. In addition, a key member of the team left the organisation before the end of the project. Consequently, the ambition for complete survey coverage of West Blean and Thornden Woods landscape within the project timeframe and subsequent data analysis was restricted. Nonetheless, useful progress was made in developing and testing the survey approach and analytical techniques to quantify structural components of habitat quality. The survey will be completed as part of the project legacy.

A number of technical limitations and potential solutions include:

- Difficulty of working within visual line of sight (VLOS) under a predominately closed tree canopy. Therefore, it is likely that a standard GVC licence will be insufficient. The Civil Aviation Authority (CAA) have recently introduced the option to gain an Extended Visual Line of Sight (EVLOS) licence, allowing the drone to be flown within 1.5 km of the pilot with the use of a spotter to maintain visual line of sight. It is likely that in order to survey the entirety of the site, the EVLOS licence will be required. This is currently not yet offered as a supplementary training course, but several organisations are working with the CAA to offer such a qualification and staff will receive this training when it becomes available.
- There are limitations around the survey time and season. For example, to survey all woodland vegetation layers, drone flights are required both during 'leaf-on' periods in the summer and during 'leaf-off' periods in the winter. To assess canopy cover, a summer survey is optimal, but to assess vegetation structure (i.e. width and height of individual trees) it may be more efficient to conduct the survey over the winter months. Further survey work will be conducted as part of the legacy of the project to gather more comprehensive data.
- Weather impacts data collection, with shadows and glare from the sun causing issues in image processing. Therefore, the quality of the images, and therefore the monitoring, will depend on images being taken at similar weather conditions at a similar time of year, which can cause operational challenges. On a sunny day, the peak time to fly surveys is around noon as the shadows are shortest, which limits the time for data collection further.
- There are several accepted methodologies for using remote sensing to monitor habitat quality, but many of these use either LiDAR or satellite imagery, and may therefore be at a coarser resolution than required for this project. To the best of our knowledge, there are no agreed metrics and common standards for the assessment of habitat quality by UAV remote sensing in the context of conservation. We recognise a need for their development, in order to make consistent, practical analysis of the data presented here within reach of practitioner organisations, and for this to be aligned with common conservation objectives for habitats at landscape-scale. A PhD research project (description below) is working towards this.

Even age structure in a beech woodland.
Image © Guy Edwardes 2020VISION



# Next steps and recommendation

- Development of common standards for the assessment of attributes of habitat quality monitored by UAV remote sensing. As remote sensing approaches to assessing habitat quality are developed, we anticipate a need to establish common metrics and assessment criteria against which habitat quality can be assessed, and to align and validate these with common standards. These will inform more specific hypotheses going forward.
- Further development and testing of approaches to assess additional attributes of habitat quality using both UAV and satellite-based remote sensing. For example, floristic content and species composition. These may be technically challenging, but with the pace of technological advancement may become achievable in the near future.
- Engagement with statutory organisations with responsibility for the natural environment to facilitate joined-up remote sensing monitoring practice.
- A collaborative (NGO/academic/government) nationwide pilot survey of habitat quality of a range of landscapes to assess the wider feasibility and application of remote sensing to landscape-scale conservation and assessment of condition, against statutory and organisational targets.
- Ground truthing of remote sensed data to improve accuracy of habitat classification and determine species-level spectral signatures, where possible.
- Cost-benefit analysis of field survey versus remote sensing approaches to determine a scale threshold for most appropriate application.
- Establishment of knowledge exchange partnerships and collaborations with academic institutions to further bridge the research-practice gap.
- National, regional, and local coordination of the gathering and application of remote sensing data to conservation applications.
- Development of fieldwork methodologies and schedule for ground-truthing remotely sensed data.
- Establishment of programmes of training, mentoring and support for the application of remote sensing in conservation practice.
- Recognition within conservation organisations of a need to recruit and/or train staff in relevant survey and analytical techniques.
- Development of comprehensive and consolidated guidance on the practical application of remote sensing by practitioners.

Further work developed as project legacy or informed by the project:

**Developing landscape-scale remote sensing approaches for monitoring conservation sites**

*Mohammed Attabou, Geographical Information Management MSc, Cranfield University.*
*Supervisors: Dr Daniel Simms and Dr Abdou Khouakhi*
*Advisor: Alison Riggs, Kent Wildlife Trust*

The project investigated which free or low-cost remote sensing data would be suitable for landscape-scale monitoring. The project includes an investigation of Global Ecosystem Dynamics Investigation (GEDI) Light Detection and Ranging (LiDAR) data which is assessed as suitable for landscape scale monitoring, alongside NDVI data from Sentinel 2 and imagery from a Planet trial. The project focussed on woodland habitats and field survey data was provided to use to calibrate, the remotely sensed data. This study demonstrated GEDI's ability to accurately sample canopy height in 25m footprints, as well as the usefulness of GEDI's waveform analysis to view canopy profile information. Fusion of airborne LiDAR with NDVI data can add value, Spot-7 multispectral imagery purchase is suggested. He proposes future research should focus on the development of an empirical model which can extrapolate GEDI derived metrics across an entire reserve. The report includes comparison tables of uses and applications of various space-borne optical, LiDAR and Synthetic Aperture Radar (SAR) sensors and of UAV sensors for conservation monitoring.

**Application of remote sensing techniques to conservation monitoring**

*Matthew Jordon, PhD candidate, University of the West of England.*
*Supervisors: Jim Vafidis, University of the West of England and Kathy Meakin, Gloucestershire Wildlife Trust.*

This project is examining how UAVs could be of more use to the Wildlife Trusts, specifically in terms of monitoring and survey of habitats, and how to incorporate remote sensing into the Trusts conservation monitoring activities. Through the assessment of current UAV usage in conservation, and the discussion of potential barriers to UAV use within Trusts, the ways in which UAVs could aid habitat monitoring and surveying can be identified. This information will then be used to carry out multiple 'proof of concept' fieldwork case studies, and further discussion will be held with Trusts to try and develop tools or solutions to barriers to application. The use of UAVs, tailored to the needs of the Wildlife Trusts, and the development of tools or solutions to aid the Trusts when using drones, will enable them to carry out monitoring more efficiently, saving time and resources that can be used elsewhere. It could also help develop common standards for using UAVs for monitoring, allowing information across different sites, and between different Trusts to be compared more easily and consistently, which would aid in larger, landscape-scale conservation. Jim Vafidis is also keen to develop affordable image analysis software tools for conservation.

# Synthesis and application

The outputs of this chapter are designed to: a) provide an overview of approaches to habitat quality monitoring using remote sensing to enable others to select scale-appropriate methods, b) detail a case study of an existing tested field survey approach  to monitoring habitat quality at landscape-scale, c) provide an overview of  the requirements for developing a UAV remote sensing approach to habitat quality monitoring at landscape-scale, d) provide a case study of a real-world example of remote sensing used at landscape-scale.

Through audit and analysis of the available technology, the development and provision of guidance though this framework, and case study, we hope to have demonstrated feasibility and provided practical guidance to enable other organisations to develop the capability to deploy UAV remote sensing techniques for the assessment of habitat quality attributes at landscape-scale. By securing resources (accepted as a significant challenge in itself) and trialling the approaches outlined and signposted here, project stakeholders have an opportunity to address some of the challenges of evidencing landscape-scale outcomes of landscape-scale conservation, using cost-to-scale effect remote sensing approaches to assessing habitat quality within their organisations. Further collaborative working and development of research practice relationships, together with engagement with appropriate statutory bodies would provide an opportunity to create and agree common standards for the use of remote sensing in habitat management and quality assessment.



# Chapter 6: JOINED

The River Stour, Sandwich Bay, Kent connecting source to sea.

# Background and rationale

Habitat loss and fragmentation are ubiquitous in both natural and human modified landscapes, resulting in detrimental consequences for biodiversity and functional processes. Development has modified over 50% of the earth's landscape, leaving only patches of isolated natural or semi-natural habitats. Patterns of biodiversity and ecosystem function are changing, resulting in a loss of connectivity and ecological integrity in ecological networks. Loss of connectivity can influence individuals, populations and communities through intra- and inter-species, and inter-ecosystem interactions. These interactions affect ecological processes such as nutrient and energy flows, predator-prey relationships, pollination, seed dispersal, demographic rescue, inbreeding avoidance, colonisation of unoccupied habitat, and alter species interactions and disease transmission. Landscape connectivity facilitates the movement of biotic processes such as animal movement, plant propagation, and genetic exchange, as well as abiotic processes such as water, energy, and material movement within and between ecosystems.

One of the key principles of the Lawton review 'Making space for Nature[1]' is summarised in the mantra 'joined'. The key approaches put forward by Lawton, and adopted by the conservation community to restore landscape connectivity, are to 'Enhance connections between, or join up, sites, either through physical corridors, or through stepping stones.' Implementing these principles is something we know how to do, but how do we know if they have delivered the outcomes we intend? There is a lack of evidence for the effectiveness of interventions to enhance connectivity. At the time of writing a key word search for "connectivity" on the www.conservationevidence.com database returned 55 conservation actions that have been assessed for their effectiveness. Of these just 25% (14) were assessed as either beneficial or likely to be beneficial (**Figure 6.1**).

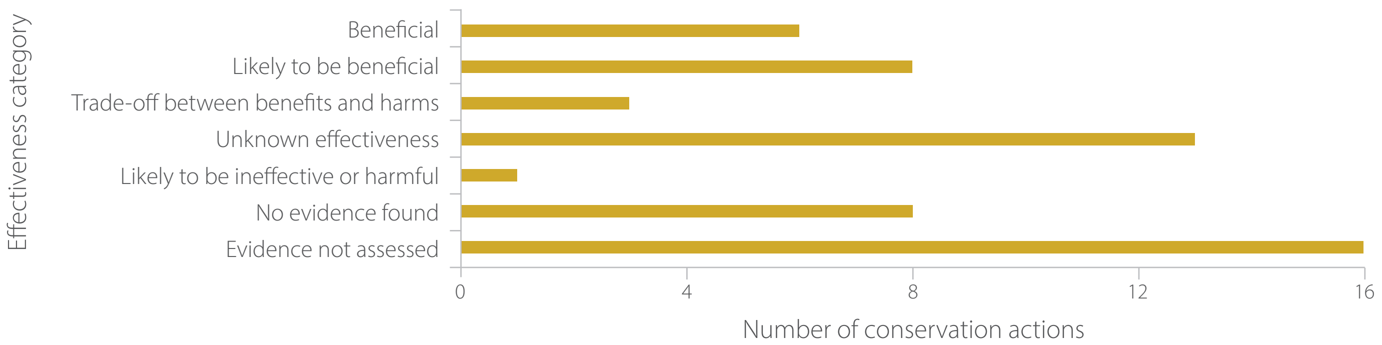



*Figure 6.1* **The number of conservation actions designed to deliver connectivity outcomes assessed in a range of effectiveness categories on the Conservation Evidence database.**

While testing the effectiveness of specific interventions on the enhancement of connectivity (causation) was beyond the scope and remit of this project, at a fundamental level there is a clear need to understand outcomes for connectivity at landscape-scale, whether causation can be shown or not.

Chalk grassland © Lucy Carden

[1] *Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.J., Tew, T.E., Varley, J., & Wynne, G.R. (2010) Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.*





## Landscape connectivity

### Landscape connectivity definitions

*The degree to which the landscape impedes or facilitates movement among resource patches[2].*

*The degree of a landscape to facilitate or impede the exchange of organisms, energy, material, and information among landscape elements. This is sometimes referred to as landscape functional connectivity, which is a function of both landscape structural connectivity and the movement characteristics of the species or process under consideration[3].*

*The functional relationship among habitat patches, owing to the spatial contagion of habitat and the movement responses of organisms to landscape structure[4].*

*The degree to which regional landscapes, encompassing a variety of natural, semi-natural, and developed land cover types, are conducive to wildlife movement and to sustain ecological processes[5].*

Landscape connectivity has both physical and behavioural components. Quantifying landscape connectivity is consequently organism-, process- and landscape-specific. The steps in the quantification of landscape connectivity are:

1. Defining the specific habitat or habitat network of the focal species and describing the landscape elements from its functional perspective.
2. Determining the scale of the landscape structure as perceived by the organism. This is defined as the scale at which the species responds to the suite of landscape elements, through its fine-scale (grain), and large-scale (extent), movement behaviours.
3. Describing how the species responds to the different elements of a landscape. This comprises the species' movement pattern based on behavioural reactions to the mortality risk and permeability of landscape elements, including habitat barriers and edges. The degree to which a landscape is connected determines the amount of dispersal there is among patches, which influences gene flow, local adaptation, extinction risk, colonisation probability, and the potential for organisms to move as they cope with climate change, habitat loss and fragmentation, and other anthropogenic threats.

### Animal movement definitions

*Daily movements:* Within a home range or territory most animals move daily among multiple primary habitat patches to forage for food and obtain resources.

*Migration:* Some species travel to different locations throughout the year to access resources. These movements are usually predictable and are due to changes in the environmental conditions at the primary habitat site, or to facilitate access to breeding grounds. Migratory behaviour is seen in land animals, birds, and marine species, and the routes they follow are usually the same year after year.

*Dispersal:* The once in a lifetime movement of certain individuals from one population to another for the purpose of breeding. These exchanges maintain genetic and demographic diversity among populations.

*Disturbance movement:* The unpredictable movement of individuals or populations to new locations of suitable habitat due to an environmental disturbance. Major disturbances such as fire, natural disasters, human development, and climate change can impact the quality and distribution of habitats and necessitate the movement of species to new locations of suitable habitat.

*Incidental movement:* Movement of species in areas that are typically used by humans. These include greenbelts, recreational/rights of way systems, hedgerows, and golf courses.

[2] *Taylor, Philip D. Fahrig, Lenore; Henein, Kringen; Merriam, Gray (1993). "Connectivity Is a Vital Element of Landscape Structure" (PDF). Oikos. 68 (3): 571. doi:10.2307/3544927.*
[3] *Wu, J. (2013) Landscape ecology. Ecological systems (ed. R. Leemans), pp. 179–200. Springer, New York, NY.*
[4] *With, K.A., Gardner, R.H. & Turner, M.G. (1997) Landscape Connectivity and Population Distributions in Heterogeneous Environments. Oikos, 78, 151–169.*
[5] *Ament, R., R. Callahan, M. McClure, M. Reuling, and G. Tabor (2014) Wildlife Connectivity: Fundamentals for conservation action (Report). Center for Large Landscape Conservation: Bozeman, Montana.*

## Connectivity metrics

Although connectivity is an intuitive concept, there is no single consistently used metric of connectivity. Theories of connectivity include consideration of both binary representations of connectivity through 'corridors' and 'linkages' and continuous representations of connectivity, which include the binary condition as a sub-set.

Generally, connectivity metrics fall into three categories:

1. *Structural* connectivity metrics are based on the physical properties of landscapes, which includes the concepts of patches (size, number of patches, average distance to each other) and relative disturbance (human structures such as roads, fragmentation, urban/agricultural land-use, human population). Landscape structural connectivity is simply a measure of how spatially connected the elements in a landscape are, without reference to any particular ecological process[6].
2. *Potential* connectivity metrics are based on the landscape structure as well as some basic information about the study organism's dispersal ability such as average dispersal distance, or dispersal 'kernel'.
3. *Functional* connectivity (also called actual or realised) metrics are measures based on the actual movements of individuals along and across contours of connectivity, including among patches (where these exist). This can take into account the actual number of individuals born at different sites, their reproduction rates, and mortality during dispersal. Some authors make a further distinction based on the number of individuals that not only disperse between sites, but that also survive to reproduce.

Connectivity modelling approaches are popular and widely used in conservation to quantify structural and potential connectivity. Conservation organisations are growing in knowledge, expertise and application of these techniques, however quantifying functional connectivity remains a challenge, and demonstrating this might be considered a gold standard in evidencing landscape-scale outcomes of landscape-scale conservation. The need to validate modelling approaches is widely recognised, though many existing field survey methods lack a strategic approach to survey design that can detect functional connectivity.

The project reviewed and assessed current modelling and field survey approaches and their application, and here we provide case studies on a two-stage approach, first modelling and quantifying potential connectivity for defined species, and then attempting to validate model outputs using a novel field survey approach. We believe this approach can be easily and flexibly applied and tested by conservation organisations in a wide variety of landscape-scale contexts.

### Connectivity modelling

Typically, connectivity as an ecological property perceived by organisms is modelled as a continuous surface of permeability, which is the corollary to disturbance. This can be accomplished by most geographic information systems (GIS) able to model in grid or raster format. A critical component of this type of modelling is the recognition that connectivity and disturbance are perceived and responded to differently by different organisms and ecological processes. This variety in responses is one of the greatest challenges in attempting to represent connectivity in spatial modelling. Often the most accurate connectivity models are for single species or processes and are developed based on information about the species or process. There is little, and often no evidence, that spatial models can represent connectivity for the many species or processes that occupy many natural landscapes.

[6] *Wu, J. (2013) Landscape ecology. Ecological systems (ed. byR. Leemans), pp. 179–200. Springer, New York, NY.*



JOINED
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps | Synthesis & application

# Development

| | |
|---|---|
| **1. Stakeholder contribution** | How stakeholders informed the design of the approach:<br>• Prioritised functional connectivity as a key theme in landscape-scale monitoring.<br>• Recommended validating modelling with a field survey approach.<br>• Guided the definition of focal landscape parameters and indicator species. |
| **2. Audit and analysis** | Through desktop research the project reviewed existing approaches to modelling connectivity, and field survey to monitor connectivity, to produce comparative analyses of methods, both for modelling connectivity, and for field survey to assess connectivity and provide validation to modelling.<br><br>Audit and analysis resulted in:<br>• Comparative analysis of modelling approaches, and application to assessing functional connectivity.<br>• Comparative analysis of field survey methods for connectivity. |
| **3. Development and testing** | **Principles**<br>The following principles were adopted in development and testing, informed by the outcomes of the stakeholder consultation and audit and analysis phases:<br><br>• Functional connectivity is the most ecologically meaningful metric of connectivity.<br>• Modelling structural and potential connectivity are valuable approaches, and more efficient than field survey approaches.<br>• A practical field survey approach is required, and the most ecologically meaningful validation of modelling approaches.<br><br>**Practical approach**<br>• **Modelling**<br>  • Based on the comparative analysis of modelling approaches, Circuitscape[7] was selected as the most appropriate tool to model connectivity of the focal landscape for focal indicator species.<br>  • Parameterise, using scientific literature and expert knowledge, habitat value and resistance scores for the focal indicator species.<br>  • Create habitat value and resistance 'surfaces'.<br>  • Either:<br>    a) Use Circuitscape-defined core population areas of focal indicator species from the parameters defined and layers above.<br>    or<br>    b) Manually select core population areas using species records and expert knowledge.<br>  • Model connectivity between the cores and quantify change in connectivity.<br>  • Compare connectivity using mapped habitat data from two points in time.<br>• **Field survey**<br>  • Based on the comparative analysis of field survey methods for connectivity the need to develop a field survey approach to detect functional connectivity was determined.<br>  • Landscape parameters defined.<br>  • Landscape focal indicator species defined.<br>  • Temporal parameter incorporated.<br>  • Survey approach designed.<br>  • Survey approach tested. |
| **4. Outputs and case studies** | The outputs of this chapter are designed to: a) provide an overview of approaches to connectivity modelling to enable others to select context-appropriate methods, b) demonstrate existing field methods lack the ability to detect functional connectivity and demonstrate the need for a new approach, c) provide an example using a case study of connectivity modelling applied in a real-world scenario, d) provide a tested field survey approach to detecting functional connectivity for species within landscapes, d) provide case studies of real-world examples of this field survey approach used at landscape-scale.<br><br>• *OP6.1* **Comparative analysis of modelling approaches, and application to assessing functional connectivity.**<br>• *OP 6.2* **Comparative assessment of the application of field survey approaches to detecting connectivity.**<br>• *OP6.3* **Case study: a practical approach to modelling and quantifying landscape connectivity for species using Circuitscape.**<br>• *OP6.4* **A practical field survey approach to detecting functional connectivity for species at landscape-scale.**<br>• *OP6.5* **Case study:testing a field survey approach to detect functional landscape connectivity using indicator species.** |

[7] *https://circuitscape.org/*

Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

JOINED
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps | Synthesis & application

# Audit and gap analysis

## OP6.1 Comparative analysis of modelling approaches, and application to assessing functional connectivity

**Key: Suitability for assessing functional habitat connectivity**
- **Green**: designed for this, **Amber**: useful but not optimal, **Red**: not designed for assessing functional habitat connectivity.

| Tool | What it does | Metrics | Data requirements | Transparency | Stage of development | Scale of coverage | Costs and IT requirements | Quantifying change | Suitability for assessing functional habitat connectivity |
|---|---|---|---|---|---|---|---|---|---|
| **BETTLE** *(Biological and Environmental Evaluation Tools for Landscape Ecology)* <br><br> *forestresearch.gov.uk/research/habitat-networks/integrated-habitat-network-modelling/* | Least-cost network model. | Connectivity indicator (0 to 1). | Land cover data and species-specific dispersal parameters and landscape permeability. | Peer reviewed, no assessment of uncertainty is available. | Mature (developed in 2003). | Can be applied to any habitat and species at any scale, although some of the parameters will not be available for many species. | Can be implemented in free software, GIS skills required. | Yes, but data availability is likely to be an issue. | An increase in the metric represents an improvement in both intra- and inter-patch connectivity in the landscape in relation to a species' requirements. The increase could be caused by habitat creation or a decrease in matrix hostility. |
| **Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust connectivity modelling tool** | Identifies connectivity using least cost paths across habitats for the species characteristics inputted. | Least cost path. | Land cover habitat type mapping and permeability scores for each habitat for the focal species. | Created by and available from BBOWT, uses ESRI's ArcGIS spatial analysist tool. | Young (developed 2018). | Can be applied to any habitat and species at any scale. | Runs in ArcGIS software, basic GIS skills required. | Possible (with data from different time periods). | Designed for this purpose, but not a finished product, and not tested to the extent of more mature tools. |
| **Circuitscape** <br><br> *circuitscape.org/* | Identifies core habitat areas and creates maps representing the cumulative connectivity between all pairwise comparisons between cores across the study area. | Circuit theory - considers effects of all possible pathways across a landscape simultaneously to produce a continuous surface of current flow (further processing e.g. with Linkage Mapper is required to identify the best linkages). | Land cover habitat type mapping and permeability scores for each habitat for the species studied to create resistance surface/habitat suitability surface/cost surface. | Methods described in a peer-reviewed 2008[8]. | Mature (developed around 2000). | Can be applied to any habitat and species (at a landscape-scale, below county-scale works best, but depends on the computer's processing power and data resolution). | Free, open source, either GUI or ArcGIS toolbox. Extra ArcGIS toolboxes provided to create input data, basic GIS skills required, no. of core areas affects processing time. | Possible (with data from different time periods). | Provides continuous surface of potential current flow (or animal movement), every possible pathway is visible, not just major corridors, pinch points readily identifiable. |
| **Conefor** <br><br> *http://conefor.org/* <br> *http://conefor.org/files/usuarios/Manual_Conefor_26.pdf* | Allows quantification of the importance of habitat areas and links for the maintenance or improvement of connectivity, as well as evaluating the impacts on connectivity of habitat and landscape change. | Indices including integral index of connectivity and probability of connectivity. | Nodes and connections (distance or probability). | Methods described peer-reviewed paper[9]. | Mature (developed 2009). | Designed for landscape-scale analyses. | Free for non-commercial use, standalone with GUI or command line interface for Windows PC, plugins for various GIS software packages available to create inputs. | Has been used for change monitoring. | This is one of tool's purposes; connectivity measure includes both intra- and inter-patch connectivity in the landscape in relation to a species' requirements. |
| **Network theory** <br><br> *https://www.researchgate.net/publication/315815263_Applying_network_theory_to_prioritize_multi-species_habitat_networks_that_are_robust_to_climate_and_land-use_change* | Uses graph theory to return metrics that measure a patches contribution to short range connectivity (persistence of spp. within a network) and long-range connectivity (maintains seasonal and climate-driven migration). The results can be imported into conservation prioritisation software (e.g. Zonation) to design protected area (or habitat) networks. | Uses graph theory the network metrics are: node's equivalent connectivity; betweenness centrality; modified betweenness centrality; current density; network's equivalent connectivity; conductance. | Land cover map and species profiles, including habitat preferences, dispersal distance and landscape resistance surfaces. | Methods are peer reviewed; an uncertainty analysis can be conducted in Zonation. | Mature. | Can potentially be applied to any habitat and species at any scale, but data availability is likely to be an issue. | Can be implemented in free software; technical skills required. | Yes, but sensitive to the choice of parameters and input data accuracy. | Measures the contribution of patches contribution to connectivity in the landscape and increases in the network metrics represent an increase in the ease with which a generic species could permeate the landscape. |

[8] *G. Varoquaux, T. Vaught, J. Millman (Eds.) 2008. Circuitscape: a tool for landscape ecology. Proceedings of the 7th Python in Science Conference pp. 62-66.*
[9] *Saura, S. & Torné, J. (2009) Conefor Sensinode 2.2: A software package for quantifying the importance of habitat patches for landscape connectivity. Environmental Modelling & Software, 24, 135–139.*



Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

JOINED
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps | Synthesis & application

| Tool | What it does | Metrics | Data requirements | Transparency | Stage of development | Scale of coverage | Costs and IT requirements | Quantifying change | Suitability for assessing functional habitat connectivity |
|---|---|---|---|---|---|---|---|---|---|
| **Condatis** Habitat network planning software. *www.condatis.org.uk/* | Maps flow routes from sources to targets, prioritises patches for protection/habitat restoration & identifies bottlenecks. | Overall flow speed; flow through each habitat cell; bottlenecks. | Land cover types; species' dispersal and reproductive parameters. | Open source and peer reviewed. | Young (first online in 2018). | Can be applied to any habitat and species. Better used at larger scales but needs under 50,000 active cells. | Free; GUI (*graphical-user interface);* analysis run at Liverpool University; some GIS skills required to make inputs. | Yes, but sensitive to poor-quality or patchy data. | Possible but requires source and target data. |
| **Connectivity Analysis Toolkit** *conservationcorridor.org/corridor-toolbox/programs-and-tools/connectivity-analysis-toolkit/* | A collection of tools. Determines priority areas for conservation measures to facilitate connectivity and dispersal and also maps the best habitat linkages between a source and a target patch. | Multiple options: Least-cost path; circuit theory/current flow; network flow. | Habitat suitability; surface/resistance; surface/cost surface (habitat and resistance are treated as a single surface). | Methods described in a scientific paper. | Young (developed 2014). | Can be applied to any habitats and species. | Free; GUI; GIS skills required to produce inputs; area studied and no. of nodes affects processing time. | Possible (with data from different time periods). | Outputs include a continuous surface of relative ease of movement but requires source and target data. |
| **Natural England National Biodiversity Climate Change Vulnerability Assessment Tool** *publications.naturalengland.org.uk/publication/5069081749225472* | Assesses the vulnerability to climate change of areas of priority habitat based on widely accepted principles of climate change adaptation for biodiversity, one is fragmentation. | Habitat fragmentation metric. | Land cover, habitat quality and conservation value data. | Methods described in a technical report; no measure of uncertainty is included. | Young. | Can be applied to any habitat at national or local scale. | Free; GUI; GIS skills required; takes around 30 minutes to assess all priority habitats in England. | Yes, can compare metrics such as area of primary habitat or network joins over time, but can be inaccurate at national boundaries and can mask local scale issues. | Does not directly measure connectivity but assesses how fragmented an area is (a reverse measure). |
| **Natural England Habitat Network Maps** *https://s3-eu-west-1.amazonaws.com/data.defra.gov.uk/Natural_England/Habitat_Species/Habitats/Habitat_Network_England_NE/* | Maps to inform habitat creation and restoration for resilient habitat networks. | Area of primary and associated habitat, network enhancement area and network joins. | None unless analysis needs to be re-run at local scale. | Methods described in a technical report; no measure of uncertainty is included. | Young (developed 2018). | Maps are available for 19 priority habitats. Local scale analyses can be implemented. | Free; GIS skills required if local scale analysis is needed. | Possible (with data from different time periods). | This is a finished product with a methodology, rather than a tool. However, the maps can be used locally to view the connectivity of areas. |
| **Population synchrony** *besjournals.onlinelibrary.wiley.com/doi/full/10.1111/j.2041-210X.2011.00098.x* | Compares population statistics for different habitat patches as a measure of connectedness. | Correlation in time-series of annual population growth rates between pairs of monitoring sites. | Population monitoring and land cover data. | Can be implemented in open source software and methods are peer reviewed; includes measures of uncertainty. | Mature. | Species-specific, but can be applied to any species, depending on data availability. | Can be implemented in free and open source software; technical skills required; not computationally intensive. | Yes, but data availability can be an issue. | Increases in metric reflect greater linkage of populations but requires detailed data on populations gathered over time. |
| **RangeShifter** *besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12162* | A platform creating integrated dynamic models of population dynamics and dispersal through landscapes across scales. | Overall patch occupancy and time lag to colonisation. | Land cover, species' distribution, dispersal and demographic parameters | Described in a scientific paper; Peer reviewed; sensitivity to parameter values and uncertainty can be assessed | Young (developed 2014). | Can be applied to any habitat and species at any scale | Free; GUI; can be difficult to parameterise | Yes, but sensitive to the choice of demographic and dispersal parameters | May be rather too precise for generalised modelling. |
| **ARCH Connectivity Assessment Tool** *Contact Tony Witts, Kent and Medway Biological Records Centre.* | Identifies connectivity using least cost paths across habitats for the species characteristics inputted. | Least cost path. | Land cover habitat type map and permeability scores. | Created by the GeoData Institute; method in the manual, available from Kent and Medway Biological Records Centre. | Young (developed 2012). | Can be applied to any habitats and species. | Can be implemented in open source software, basic GIS skills required. | Yes (with data from different time periods). | Maps corridors rather than whole landscape permeability. |

JOINED
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps | Synthesis & application

| Tool | What it does | Metrics | Data requirements | Transparency | Stage of development | Scale of coverage | Costs and IT requirements | Quantifying change | Suitability for assessing functional habitat connectivity |
|---|---|---|---|---|---|---|---|---|---|
| **Corridor Designer** <br> www.corridordesign.org/ | Toolbox for creating habitat and corridor models and an extension for evaluating them. | Least cost path. Corridor evaluation metrics: width and bottlenecks, distances between habitat patches, histograms of habitat suitability. | Habitat suitability surface (built within the toolkit). | Approach described in scientific report, many experts consulted during development. | Relatively mature (developed between 2001-2006). | Regional (e.g. 2 - 500 km long) scale. | Free, ArcGIS toolbox. | Possible (with data from different time periods). | Maps corridors rather than general landscape permeability. |
| **LinkageMapper** <br> circuitscape.org/linkagemapper/ | Uses GIS maps of core habitat areas and resistances to identify and map linkages between core areas. | Hybridizes circuit theory and least cost path. | Areas of habitat to be connected. Resistance surface/habitat suitability surface/cost surface. | Methods described and peer tested. | Mature (similar to Circuitscape). | Can be applied to under 9999 core areas of habitat at any scale. | Free, open source, under GNU[10] General Public License; provided as ArcGIS Toolbox (requires Spatial Analyst extension). | Yes (with data from different time periods). | Intended to find links not whole landscape connectivity. |
| **Marxan** – software for systematic conservation planning <br> http://marxan.org/ | Multiple tools including one using the principle of complementarity to select planning units which complement a conservation area network. | Cost of achieving conservation targets. | Data on the planning area, habitat patches and their cost and conservation features (species). | Open source and peer reviewed; includes a sensitivity analysis; does not consider uncertainty in the data. | Mature (developed 2000). | Can be applied to any habitat and species at any scale. | Free; graphical user interface; GIS skills and knowledge of the software required, no. of planning units and cons features affect processing time. | Yes, but sensitive to spatial bias in the data. | Based around spatial planning for reserve networks rather than the wider landscape. |
| **MulTyLink** <br> conservationcorridor.org/corridor-toolbox/programs-and-tools/multylink/ https://www.sciencedirect.com/science/article/pii/S1364815212002113 | Models landscape connectivity for multiple species in complex heterogeneous landscapes, and selects linkages for distinct types of habitats. | Least cost path. | Resistance layer. | Methods described in scientific paper[11]. | Not easily available now (developed 2012). | Can be applied to different habitats and species. | Free, C++ open source program works with ArcGIS. | Possible (with data from different time periods). | Looks at linkages and barriers rather than general landscape permeability. |
| **Zonation** <br> conservationcorridor.org/corridor-toolbox/programs-and-tools/zonation/ | Software for conservation prioritisation. | Conservation value of habitat network through a replacement cost analysis. | Spatial data on the planning area and each biodiversity feature of interest (species or habitats). | Open source and peer reviewed; includes an assessment of uncertainty. | Mature (developed in 2006). | Can be applied to any habitat and species at any scale, optimised for larger datasets. | Free; graphical user interface; GIS skills and familiarity with the software required. | Yes, but sensitive to poor-quality or patchy data. | Does not directly measure connectivity but prioritises areas for improvement. |

**Notes:** The processing time for majority of tools will varies with size and resolution of the landscape data considered.
Table produced with thanks and credit to Centre for Ecology and Hydrology and Surrey Wildlife Trust.
Useful resources: http://corridordesign.org/designing_corridors, http://www.landscope.org/focus/connectivity/,
Information on creating resistance or core area layers: https://circuitscape.org/gnarly-landscape-utilities/,
http://conservationcorridor.org/library/

[10] https://en.wikipedia.org/wiki/GNU
[11] Brás, R., Cerdeira, J.O., Alagador, D. & Araújo, M.B. (2013) Linking habitats for multiple species. Environmental Modelling & Software, 40, 336–339. https://doi.org/10.1016/j.envsoft.2012.08.001

# Practical approach: connectivity modelling

## OP6.3 Case study: a practical approach to modelling and quantifying landscape connectivity for species using Circuitscape

### Introduction

The project sought to develop a practical modelling approach to quantify theoretical connectivity for defined indicator species within a focal landscape. Development was informed by the steps defined in **Chapter 3.**

| | | | | | | |
|---|---|---|---|---|---|---|
| **1. Define landscape parameters** | **2. Define theme to be addressed** | **3. Articulate objective, question or hypothesis** | **4. Specify required data** | **5. Attributes of monitoring programme** | **6. Selecting indicator(s)** | **7. Develop practical approach** |

**1. Define landscape parameters:** the parameters of the focal landscape were defined as the entire extent of chalk grassland habitat in Kent.

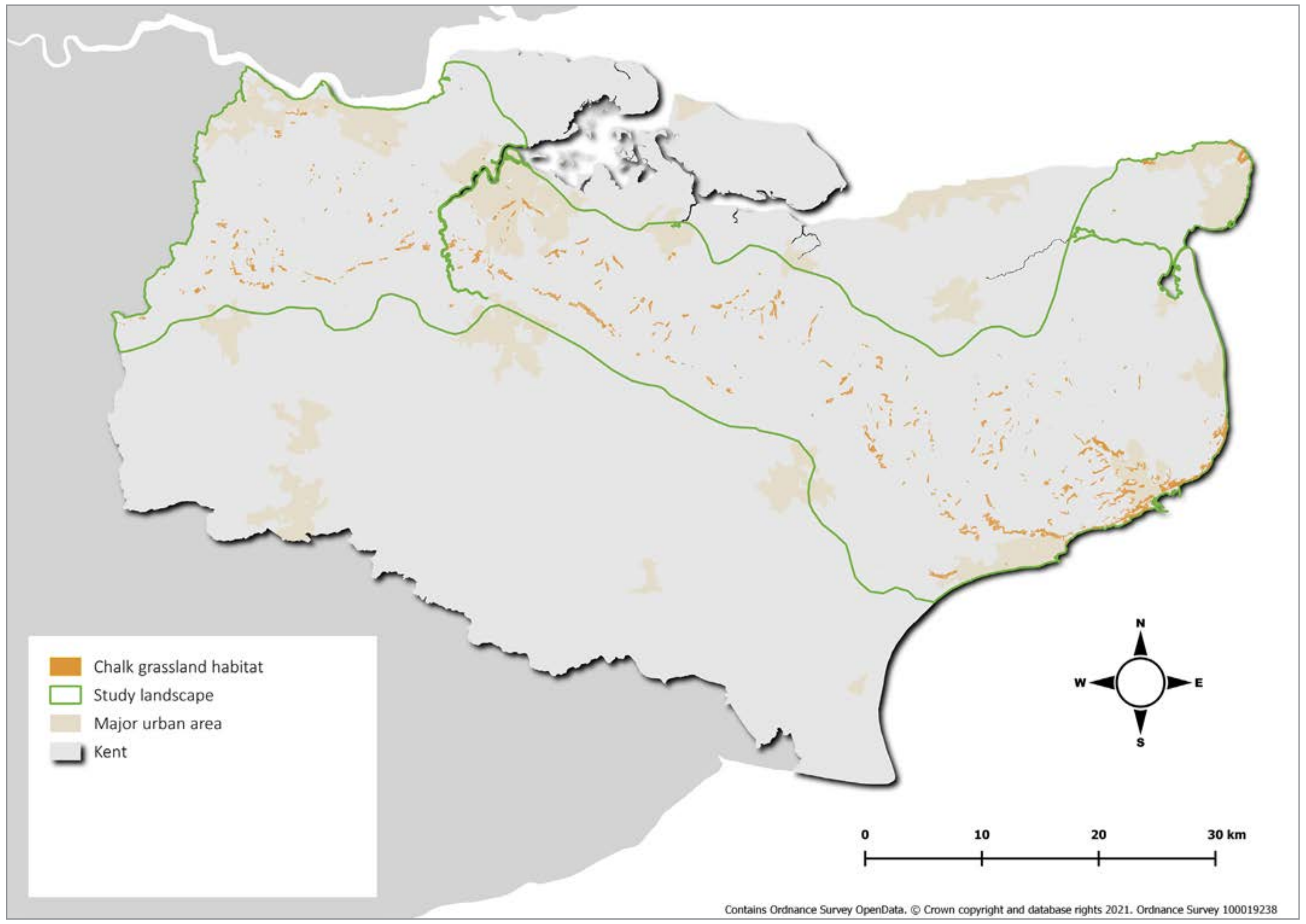



*Figure 6.2* **Extent of chalk grassland habitat in Kent.**

Connectivity is not constrained by lines artificially drawn around project areas on maps. How the study landscape is defined will determine what can and cannot be interpreted from the data. Defining a study landscape in which connectivity is constrained in some way, such as by the extent of a habitat type of interest, geographical isolation, physical barriers such as transport infrastructure or geophysical features, will permit creation of more reliable models than for landscapes in which connectivity is contiguous with areas outside of a defined study area. See **OP3.2 Guiding principles for defining landscape parameters.**





**2. Define theme to be addressed:** theoretical connectivity; evidence that a landscape has improved in its capacity to facilitate the dispersal of species. **See OP3.4 Defining monitoring themes and rationale.**

**3. Articulate objective, question or hypothesis:** the objective of this approach is to determine whether functional connectivity within a landscape has changed as a result of conservation effort. **See OP3.6 Articulating the question and hypothesis testing.**

The null and alternative hypotheses were defined as:

- H0: there is no evidence of any change in connectivity within the study landscape.
- H1: there is evidence of change in connectivity within the study landscape.

**4. Attributes of monitoring programme:** As a modelling rather than a survey approach was adopted here, it was not deemed necessary to consider the desirable attributes of monitoring programmes which relate more to field survey. **See OP3.3 Ordered list of attributes of monitoring programmes.**

**5. Selecting indicator species(s):** The decision of what species are suitable to monitor in order to detect functional connectivity can be a daunting and challenging task. The project produced a set of criteria for selecting landscape-scale indicators collaboratively with project stakeholders. This created a consensus on the required parameters from within the conservation community and provides a common framework for comparison of landscape-scale connectivity studies. The criteria can be used in conjunction with information on the ecology of candidate indicator species and expert knowledge, to select suitable indicator species. **See OP3.7 Criteria for selecting landscape scale indicators**.

Focal taxa were chosen to reflect temporal variability in dispersal. Taxa with relatively fast dispersal ecology (butterflies) and relatively slow dispersal ecology (reptiles) were chosen. The next step was to choose appropriate species. Establishing the *Criteria for selecting landscape-scale indicators* (*OP3.7*) informed the choice of suitable species indicator for the defined landscape-scale parameters, theme and objective. The main factor in this approach was selecting a species with a dispersal mechanism or ecology that relies on our chosen landscape-scale parameter, the chalk grassland within the North Kent Downs. The focal indicator species of butterfly selected was the Adonis blue *Polyommatus bellargus* and reptile, the European adder[12] *Vipera berus*.

### Adonis blue

The Adonis blue butterfly is a specialist of unimproved southern chalk downland and is a species that underwent a rapid decline in the 1950s to 1970s across its range in the UK. This decline led to an increase in research on its dispersal mechanisms and ecology. With simple training, the species can be reliably identified simply and cheaply in the field using critical features and established survey techniques. The Adonis blue is a species at which conservation effort is targeted widely in Kent, and colony numbers appear to be increasing as a result of grassland management. As a short-lived bivoltine species with short generation times it has the potential to respond quickly to management, and despite susceptibility to population fluctuation resulting from natural variation in the weather, population signals are not sufficiently obscured to prevent detection of responses to management. As a chalk grassland specialist that requires specific habitat attributes, it can provide meaningful information about landscape-scale biodiversity outcomes in the focal landscape. Adonis blue is widespread within the focal landscape, and sufficiently common to be detected in multiple patches, but not so common that it occupies every patch of

Adonis blue, male, © Collin Williams

suitable habitat, allowing new instances of colonisation to be detected. Butterflies are widely monitored through existing schemes using established methods, providing good baseline data, and widespread recognition and understanding of results by policy makers and practitioners. It was recommended as a suitable focal indicator species by Butterfly Conservation through the project technical advisory group, and it is a priority species identified in the Kent Biodiversity Strategy[13].

[12] *While not a chalk grassland specialist, the European adder has strong association with chalk grassland in Kent.*
[13] *https://www.kentnature.org.uk/biodiversity-strategy.html*

## European adder

The European adder is found extensively across the UK, and recent declines especially in central England, mean it is of major conservation concern. Its ecology is well understood, and dispersal has been a particular focus of studies by Kent Reptile and Amphibian Group (KRAG). With simple training, the species can be reliably identified simply and cheaply in the field using critical features and established survey techniques. Conservation effort is widely targeted at the species in Kent. In contrast to butterflies, adders reproduce less frequently and disperse more slowly. Studies by KRAG have found dispersal from occupied to adjacent patches can take in excess of ten years. Being long-lived, they are less susceptible to short-term fluctuation due to natural variation, though responses to conservation efforts can occur within meaningful timeframes, and the selection of adder provides a contrasting assessment of temporal dispersal compared to butterflies. Adders are not evenly distributed in Kent and show a close association with chalk grassland. Consequently, they can provide meaningful information about conservation outcomes in the focal landscape. Adders are found throughout the focal landscape and are sufficiently common to be detected in multiple patches, but not so common that they occupy every patch of suitable habitat, allowing new instances of colonisation to be detected. Reptiles are widely monitored through existing schemes using established methods, providing good baseline data, and widespread recognition and understanding of results by policy makers and practitioners. Adder was recommended as a suitable focal indicator species by KRAG through the project technical advisory group, and it is a priority species identified in the Kent Biodiversity Strategy[14].

Adder, © Lee Brady

**6. Practical modelling approach:**

**a. Selection of modelling tool:** Circuitscape was selected based on the information presented in **OP6.1 Comparative analysis of modelling approaches, and application to assessing functional connectivity.** Circuitscape is free, creates a visually interpretable map output, and doesn't require the user to create fixed start and end points to calculate a path between, so deals well with landscape connectivity. It doesn't require any programming experience. ArcGIS toolboxes are provided to create the inputs. We were greatly encouraged by Surrey Wildlife Trust's use of Circuitscape successfully for a similar project[15], and as a neighbouring county, it made sense to use comparable methods. Since completion of this work, a new version of Circuitscape has been released written in Julia[16] which Surrey Wildlife Trust have found to be more efficient and effective. Circuitscape is based on circuit theory in which the ecological flow of genes is analogised to current and resistance in electrical circuits.

**b. Software required:** ArcGIS is required to run the toolboxes, though any GIS software can be used to view the resulting map outputs.

**c. Habitat data inputs and formatting;** A complete habitat layer in vector format for the focal landscape is required. Kent benefits from several county-wide habitat surveys. The habitat data used in the analysis was obtained from the 2003 Kent Habitat Survey and the 2012 ARCH Kent Habitat Survey[17], providing the opportunity for a temporal comparison.

- The Circuitscape user guide is helpful and was augmented by support from Surrey Wildlife Trust.
- Circuitscape provides ArcGIS toolboxes ('Resistance and Habitat Calculator' and 'Core Mapper' in the 'Gnarly Utilities' download,) which produce the raster and vector inputs for the Circuitscape (non-GIS based) tool itself. Another ArcGIS Toolbox runs in ArcCatalog and connects to the Circuitscape tool itself, so everything can be performed within ArcCatalog.
- The only essential formatting required to the habitat vector layer is to ensure each unique habitat type has a unique number in a 'ClassID' field.
- Then, before using the 'Resistance and Habitat Calculator' toolbox it is necessary to create a .csv file of habitat value and resistance scores for each ClassID (habitat type) present in the habitat layer, for each of the focal indicator species. The toolbox creates a 'habitat resistance surface[18]' using the parameters for each habitat that the user entered as the .csv file and the habitat polygon layer input. See example for adder in **Figures 6.3**.

*[14] https://www.kentnature.org.uk/biodiversity-strategy.html*
*[15] Siggery, B., Waite, M., Guilliatt, M. & Fekri, S. (2019) A methodology for quantifying and measuring connectivity across Surrey and beyond. Research & Monitoring Department, Surrey Wildlife Trust.*
*[16] Circuitscape 5 https://circuitscape.org/downloads/ is developed in Julia https://julialang.org/ for better performance and scalability. Julia is a modern open-source language for scientific computing. https://docs.circuitscape.org/Circuitscape.jl/latest/*
*[17] For further info on Kent's habitat surveys see https://www.kent.gov.uk/environment-waste-and-planning/planning-and-land/kent-landscape-information-system/resources/klis-habitat-survey-data-resources and https://www.kent.gov.uk/business/business-loans-and-funding/eu-funding/assessing-regional-habitat-change*
*[18] A GIS raster layer in which each cell is parameterised with a value or values of the permeability of the cell to the phenomenon (in this case a species) being modelled.*





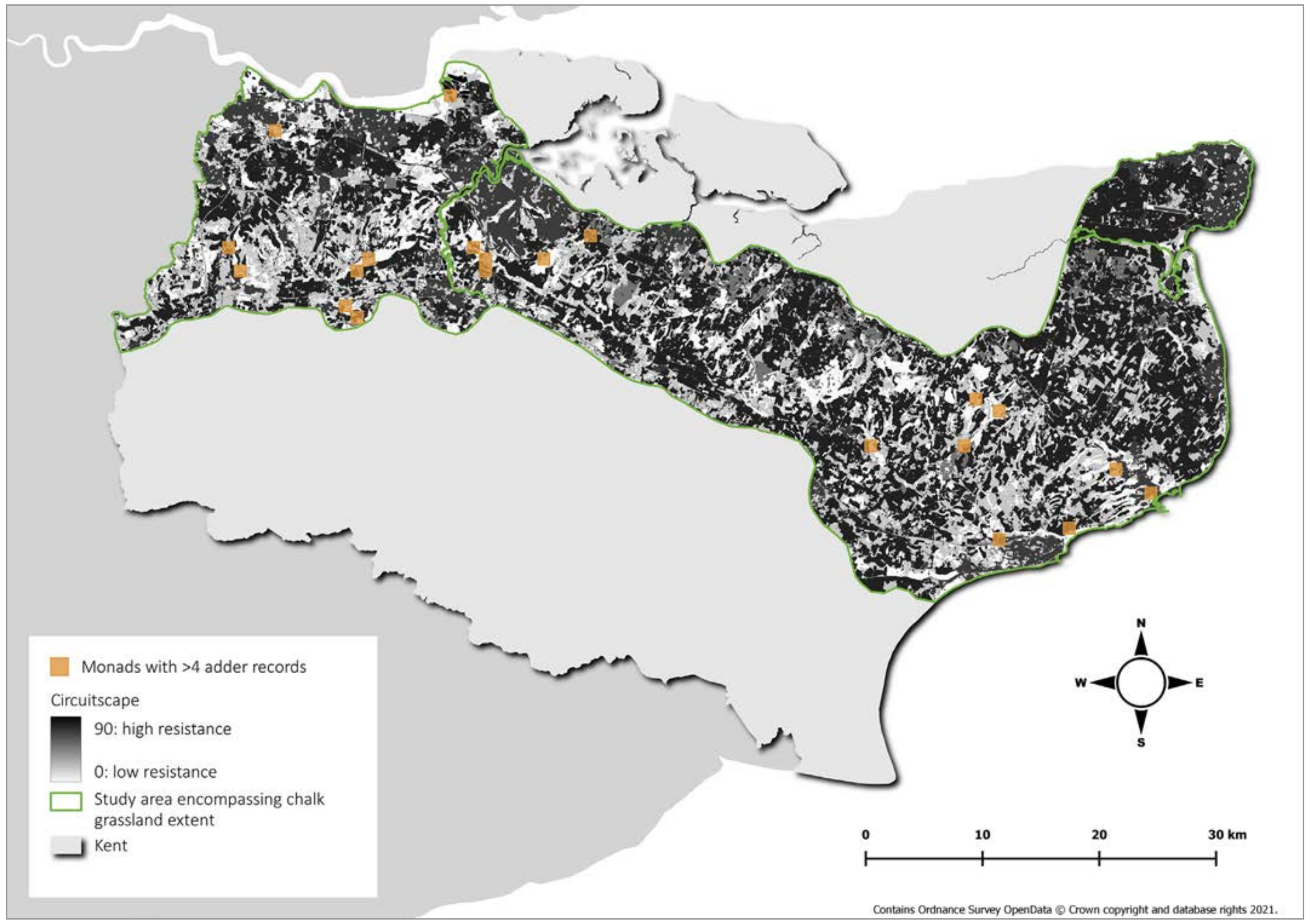



*Figure 6.3* **Circuitscape resistance surface created using 2003 Kent Habitat Survey data and resistance scores for adder.**

**d. Species information required:** The indigenous knowledge of species conservation groups was key to defining habitat value and resistance scores for each habitat type. For the purpose of comparison of connectivity over time, Circuitscape created 'cores'[19] in different areas for each habitat layer and year. Upon visual inspection they did not match well with species records, therefore it was decided to manually select monads (1 km squares) to use as cores, defined by the frequency of existing records of the focal indicator species. Records were obtained from the Local Environment Record Centre (Kent and Medway Biological Records Centre) and advice sought from county species recording groups on suitable thresholds for core areas. The number of individuals reported from a single visit was deemed more important than frequency of records at a location.

Ecologically meaningful abundance thresholds were advised by Butterfly Conservation and Kent Reptile and Amphibian Group respectively (see Figure 6.4 and 6.5 for percentage frequency of records). All applicable monads were selected on this basis and used as cores in the models. A threshold of four adders and ten Adonis blue individuals selected 21 and 26 monads respectively, and these were used as the cores in the models. For adder, an alternative approach might be to consider the survey methodology used for each record: if two or more adders were observed during visual searches this may indicate a better site than four observed by examining refugia. A last resort might be use simple expert judgement-based experience and habitat assessment, however this is somewhat subjective. For butterflies, it should be noted that when a new site is colonised, only single figures may be observed in the first instance.

*[19] Circuitscape 'cores' are areas of high suitability for the species modelled based on the parameters inputted.*

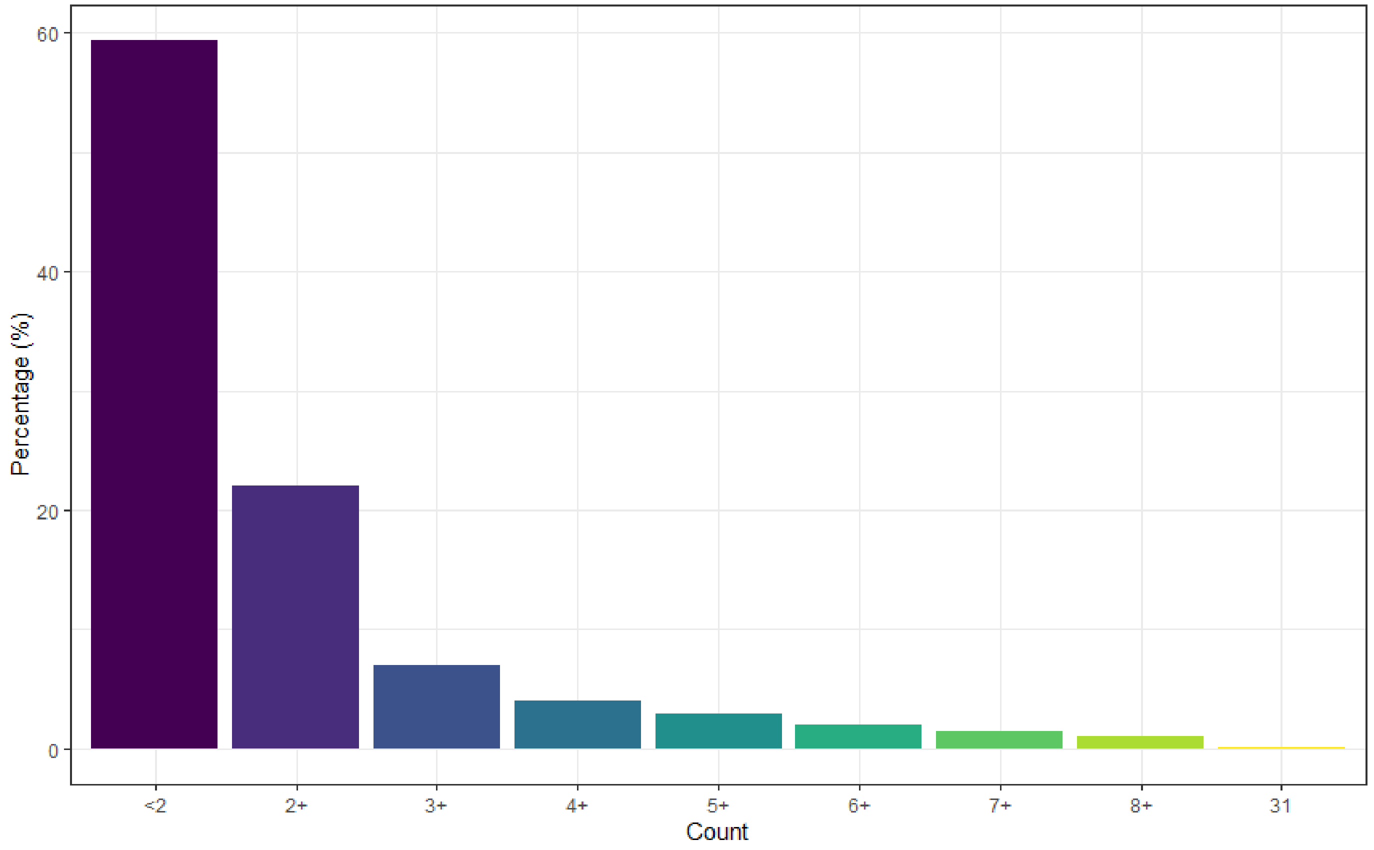



*Figure 6.4* **Percentage frequency of adder records from 2005-2020 used to determine abundance thresholds for core area selection to parametrise connectivity modelling.**

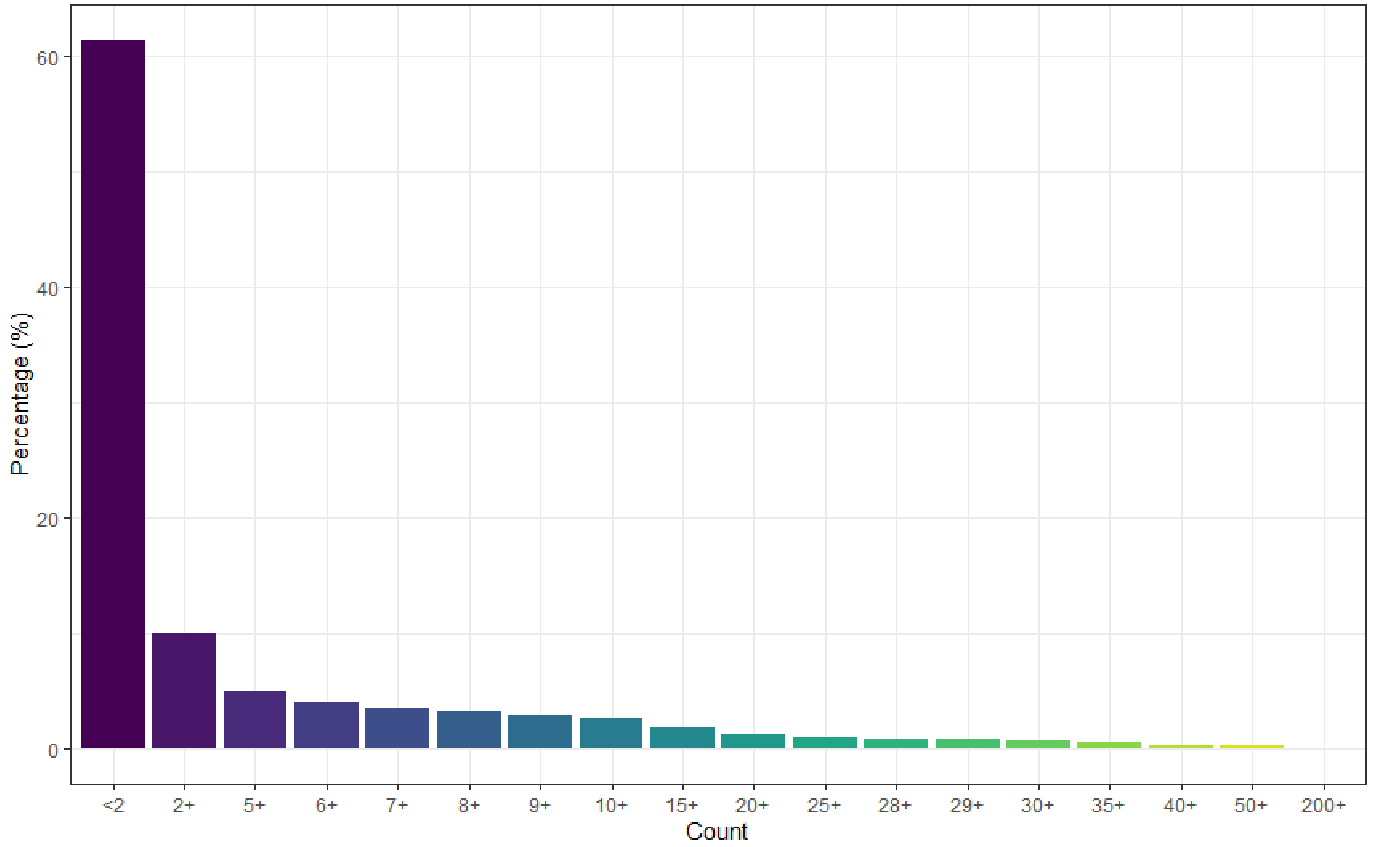



*Figure 6.5* **Percentage frequency of Adonis blue records from 2005-2020 used to determine abundance thresholds for core area selection to parametrise connectivity modelling.**





## Comparing connectivity values

The maps produced by Circuitscape show habitat connectivity at the landscape scale (See Figures 6.6 to 6.9). To make comparisons between the connectivity results, numerical values[20] were derived following Siggery et al (2019)[21]. The ArcGIS 'Raster to Point' tool was used to obtain a list of the values of each cell in the current map raster output layer. Then, all values greater than or equal to 1 were selected (grid_code >=1) and then the mean figure calculated. As per Siggery et al, all values less than 1 were excluded from the mean, as these habitats were classed as impermeable. The resulting outputs are presented in **Table 6.1**.

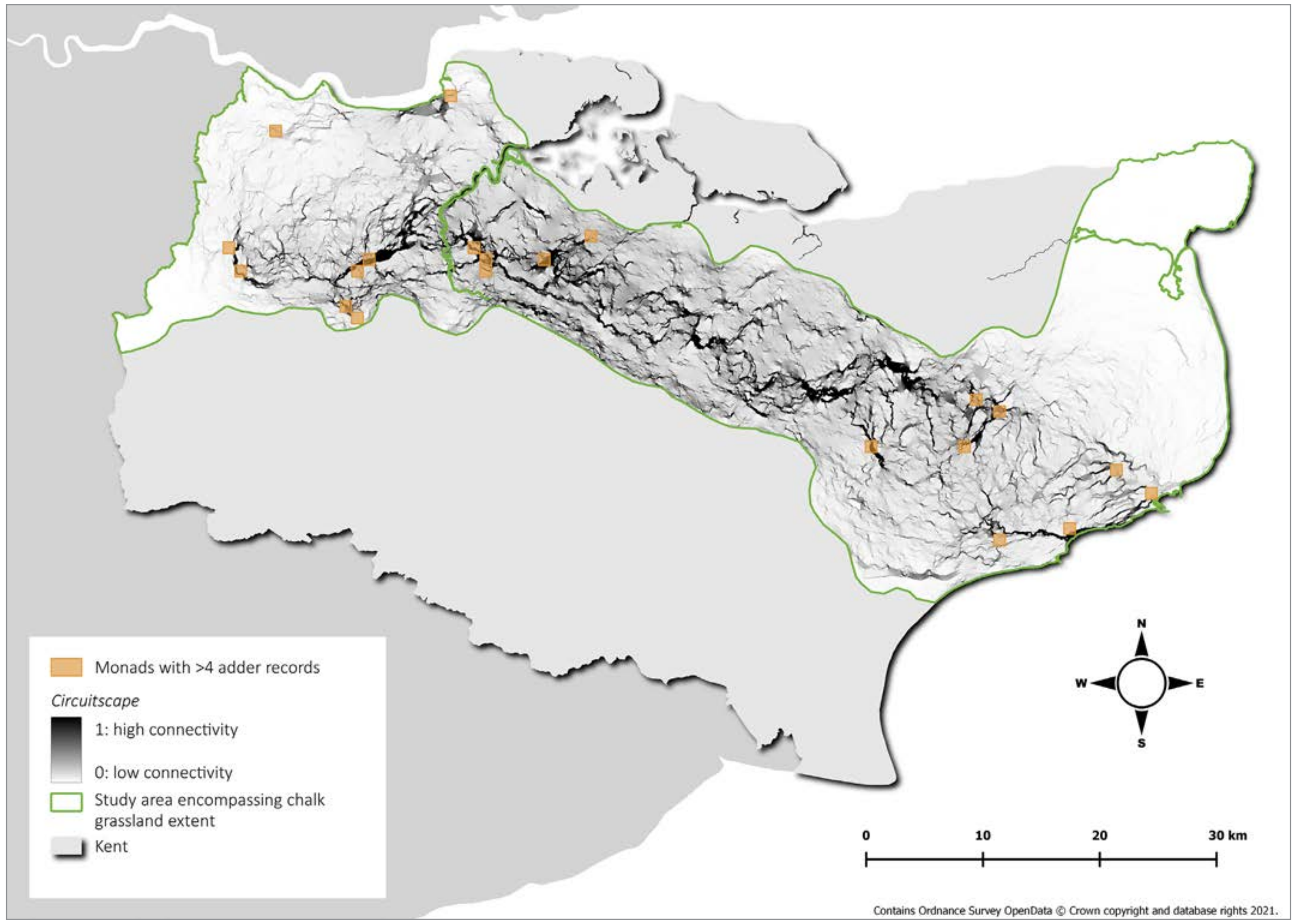



*Figure 6.6* **Circuitscape output with 2003 Kent Habitat Survey data and cores created from monads with records of more than four adders in one record.**


Chalk grassland in bloom © Guy Edwardes 2020Vision

[20] *A raster overlay analysis would provide an alternative approach.*
[21] *Siggery, B., Waite, M., Guilliatt, M. & Fekri, S. (2019) A methodology for quantifying and measuring connectivity across Surrey and beyond. Research & Monitoring Dept. Report. Surrey Wildlife Trust*

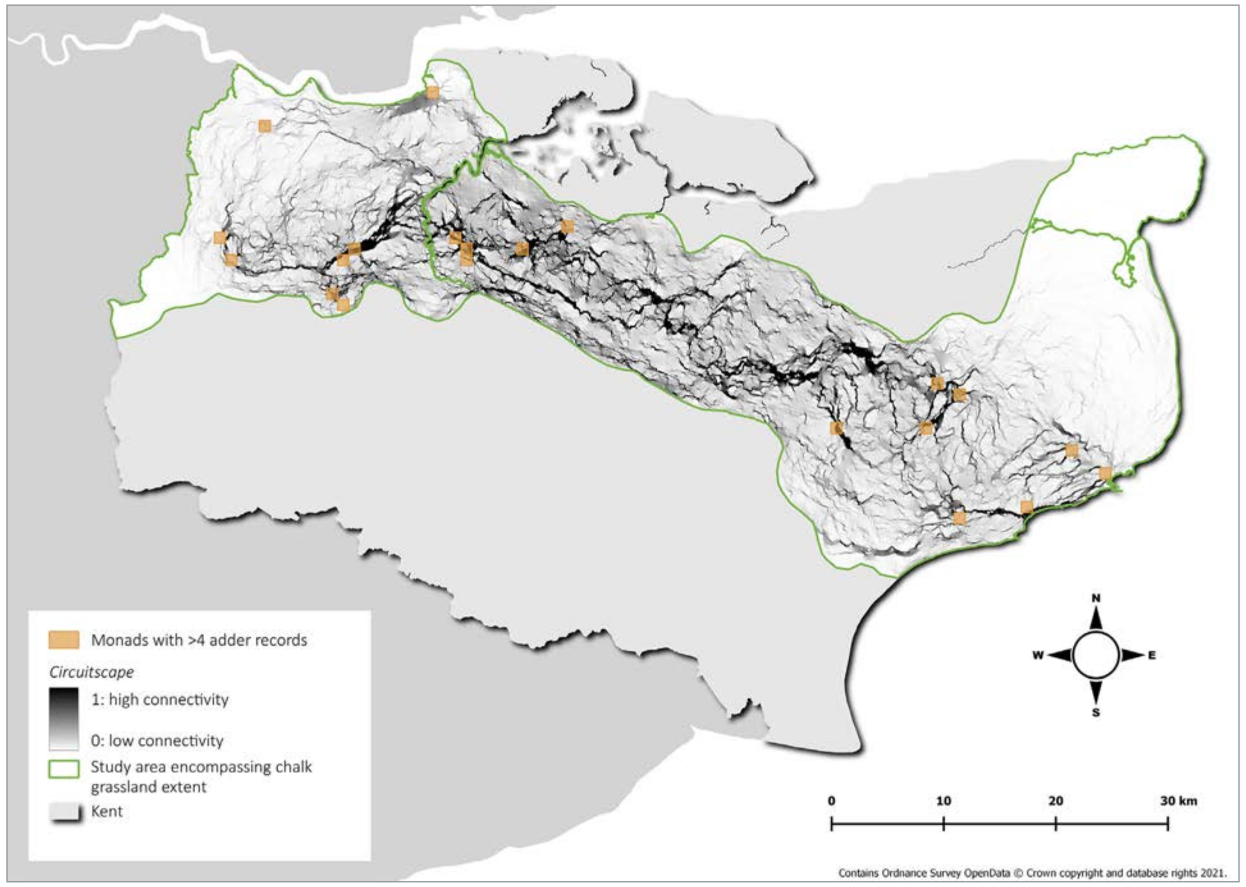



*Figure 6.7* **Circuitscape output with 2012 ARCH Kent Habitat Survey data and cores created from monads with records of more than four adders in one record.**

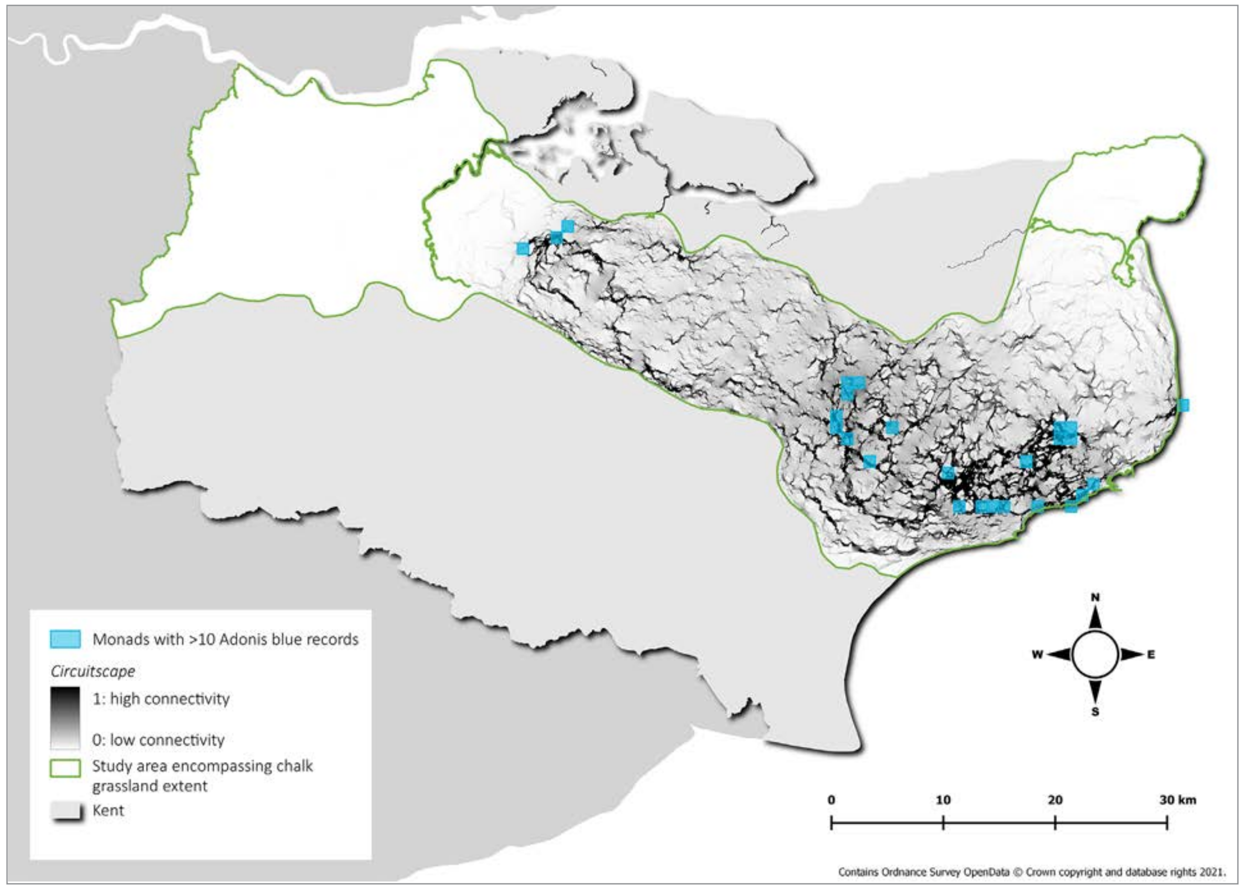



*Figure 6.8* **Circuitscape output with 2003 Kent Habitat Survey data and cores created from monads with records of more than ten Adonis blue in one record.**



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Background & rationale | Development | Audit & gap analysis | Practical approach | Functional connectivity | Limitations | Next steps | Synthesis & application

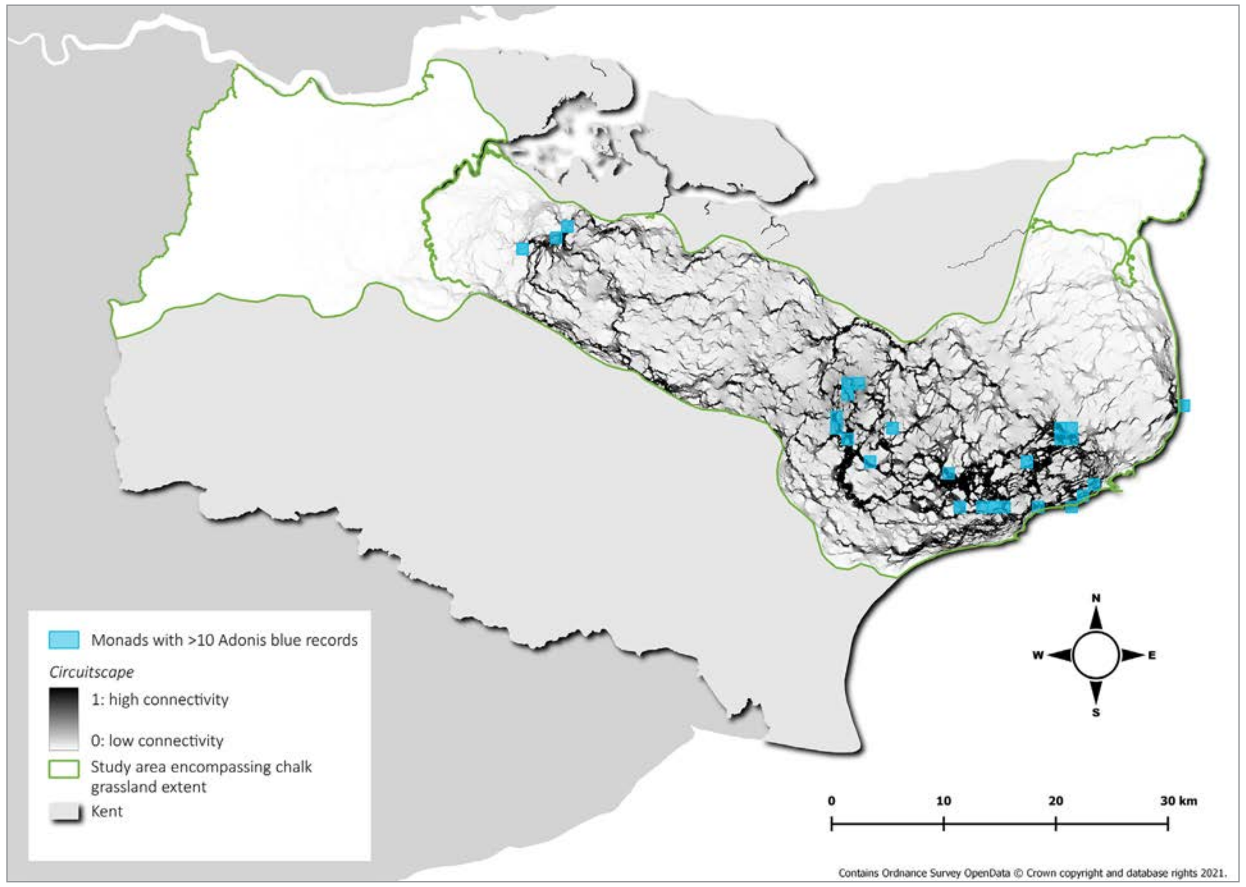


*Figure 6.9* **Circuitscape output with 2012 ARCH Kent Habitat Survey data and cores created from monads with records of more than 10 Adonis blue in one record.**

*Table 6.1* **Connectivity values derived using Circuitscape modeling of landscape connectivity for adder and Adonis blue in the North Kent Downs in 2003 and 2012, using mapped habitat data.**

| Input cores | 2003 | 2012 |
|---|---|---|
| **Adder** | | |
| Circuitscape derived cores | 1.222 | 2.594 |
| Cores as monads containing at least 1 record with more than 4 adders in one sighting | 1.706 (Figure 6.6) | 1.618 (Figure 6.7) |
| **Adonis blue** | | |
| Circuitscape derived cores | 1.469 | 1.511 |
| Cores as monads containing at least 1 record with more than 10 Adonis blue in one sighting | 1.869 (Figure 6.8) | 1.789 (Figure 6.9) |

These results appear to indicate reduced connectivity from 2003 to 2012 for the monads of records as cores, suggesting that the alternative hypothesis (H1: there is evidence of change in connectivity within the study landscape) can be accepted. Circuitscape derived cores were considered less ecologically meaningful, and the resulting figures less likely to be an accurate reflection of true landscape connectivity than the cores defined by biological records and local knowledge and expertise. However, it should be noted that the 2003 habitat survey data was digitised at a coarser resolution than in 2012, because for the 2003 data the habitat polygons were manually digitised whereas the 2012 survey populated Ordnance Survey MasterMap polygons. This means, for example, smaller greenspaces within urban areas are resolved in 2012 (instead of a whole town being categorised as built environment in 2003) making them appear permeable in the Circuitscape outputs for 2012 data but this may not be genuine change between time periods, just an artefact of the detail of the input habitat data. Interestingly, it does demonstrate how increases in urban green space influence permeability. Limitations, next steps and synthesis and application are discussed below.

# Functional connectivity – field survey

## OP6.4 A practical field survey approach to detecting functional connectivity for species at landscape-scale

### Survey design

The project sought to develop a practical field survey approach to validating the outputs of connectivity modelling by attempting to quantify functional connectivity. Development was informed by the steps defined in Chapter 3 and sought to develop a strategic approach to designing surveys that incorporate indicator species selection, known range, potential range and prior species absence at patch scale within a focal landscape, to enable the detection of functional connectivity: evidence of species permeating a landscape to occupy previously unoccupied patches.

| 1. Define landscape parameters | 2. Define theme to be addressed | 3. Articulate objective, question or hypothesis | 4. Specify required data | 5. Attributes of monitoring programme | 6. Selecting indicator(s) | 7. Develop practical approach |
|---|---|---|---|---|---|---|

**1. Define landscape parameters:** the parameters of the study landscape were defined as the entire extent of chalk grassland habitat in Kent (Figure 6.2).

**2. Define theme to be addressed:** functional connectivity; evidence that a landscape has improved in its capacity to facilitate the movement of species within it.

**3. Articulate objective, question or hypothesis:** the objective of this approach is to determine whether functional connectivity within a landscape has changed as a result of conservation effort. It is important to articulate the specific objective, question or hypothesis. See **OP3.6 Articulating the question and hypothesis testing**.

An example of a null and alternative hypothesis might be:

- H0: there is no evidence of species occupying previously unoccupied patches within the study landscape.
- H1: there is evidence of species occupying previously unoccupied patches within the study landscape.

**4. Attributes of monitoring programme:** The survey design for the approach considered the desirable attributes of monitoring programmes. **See OP3.3 Ordered list of attributes of monitoring programmes** and **OP6.5.**

**5. Selecting indicator species(s):** The decision of what species are suitable to monitor in order to detect functional connectivity can be a daunting and challenging task. The project produced a set of criteria for selecting landscape-scale indicators collaboratively with project stakeholders. This created a consensus on the required parameters from within the conservation community and provides a common framework for comparison of landscape-scale connectivity studies. The criteria can be used in conjunction with information on the ecology of candidate indicator species and expert knowledge, to select suitable indicator species. See **OP3.7 Criteria for selecting landscape scale indicators**.

**6. Practical approach: The Survey Site Selection Equation**
The project sought to create a simple equation to define target survey locations to detect functional connectivity for a focal indicator species within a landscape:

*Target survey locations =*
*(potential range - known range) + known absence + spatial dispersal potential + temporal dispersal potential*





### Where:

*Target survey locations* = locations in which recording the focal indicator species will demonstrate functional connectivity.

*Potential range* = the spatial extent of potential occupation by the chosen indicator species, i.e. occupied geographic range or extent of suitable habitat. This may be constrained within the defined landscape if occupied geographic range or extent of suitable habitat extend out with the landscape boundary defined. Derived from mapped habitat data, satellite imagery or other suitable sources.

*Known range* = the known range of the chosen indicator species within the defined landscape boundary, derived from sources of existing data such as the relevant Local Environmental Records Centre, NBN Gateway, or species recording groups.

*Known absence* = the spatial extent in which sufficient survey effort has been conducted to provide reasonable confidence of absence of the chosen indicator species. Simply finding the target species in a location it has not been recorded before is not proof of dispersal to that location; it may simply be that it has never been searched for there. A temporal period of survey effort to determine absence should be defined, i.e. preceding 10/50/100 years, informed by knowledge of landscape and species history.

*Spatial dispersal potential* = the spatial range over which, given its dispersal ecology, the chosen indicator species might be expected to disperse from its known range. Target survey locations must be within expected dispersal distance of the species from its known range. Searching outside of this range has the potential to be wasted effort.

*Temporal dispersal potential* = the temporal range over which the chosen indicator species might be expected to disperse from its known range. This will be influenced by reproductive rate, dispersal mechanism and habitat specialism. Species with rapid dispersal may take a relatively few years to arrive at target survey locations, while species with slow dispersal may take many years. For example, we might expect it would take longer for a reptile to colonise new patches within a landscape than a bird or butterfly. An understanding of the dispersal ecology of the chosen indicator species is essential. Temporal dispersal potential is used to inform both the timing and duration of survey effort over a period of years required to give confidence in the likelihood of detecting functional connectivity

### Additional considerations

*Spatial resolution:* Working at a landscape-scale requires consideration of a suitable resolution at which to monitor the focal indicator species. The chosen resolution must balance the gathering of ecologically meaningful patch occupancy for the species, with the resourcing of survey effort required, and the resolution of the available data for current distribution. A species with low *spatial dispersal* potential might warrant finer scale resolution, and a species with high *spatial dispersal* potential a coarse resolution. A useful rule of thumb, aligned with national and county-scale distribution mapping, is to use a 10km grid at country-scales, and 1km at county-scales. At sub county-scale, 1km, or smaller resolution may be required. The choice needs to carefully consider the resolution of available data, and what would be ecologically meaningful for the focal species. If data on the known range are not available at an appropriate resolution, survey design might incorporate baseline data collection of known range at the appropriate scale as a first step.

*Patch size:* The final selection of *target survey locations* should include an element of sense checking the size of selected patches. Any patches that below a threshold that is unlikely to support the indicator species in an ecologically meaningful way, should be removed from the candidate list of survey locations.

### 7. Survey method

**Method choice**
Field survey methods are not inherently unsuitable for monitoring connectivity, but often lack a strategic approach or direction to their design that can allow functional connectivity can be detected. Once the design of the survey is established through steps 1-7, the next stage is to define a suitable survey method, how this will be resourced, and how the data will be analysed. Typically established survey methods are likely to be the most suitable with which to monitor *target survey locations*. Considerations around choice of survey method, resourcing data collection, recruitment, training and support of participants, equipment, data integrity and validation are typically well understood by practitioners and considered unnecessary to include in detail here. Detail of the approaches taken in the testing of this approach are outlined in the case study in this chapter.

## Worked example

**Practical application of survey site selection equation using GIS. In the long term this process will be automated using the statistical software 'R'[11]**

*a) Potential range*

Import a layer containing the mapped extent of suitable habitat informed by the choice of indicator species. In this example Adonis blue and chalk grassland are used. The extent of chalk grassland within the North Kent Downs encompasses the potential functional connectivity of Adonis blue within a defined landscape area.

*b) Known range*

Import a layer containing all records of the focal indicator species. Consider the temporal relevance of records to the history of landscape management and fragmentation. Records that pre-date the timescale of conservation intervention might be excluded from survey design: i.e. a recent rather than a historic known range should be used. In this example, only records within the 10 years prior to the planned survey are included.

*c) Known absence*

Define a number of years in which survey effort for the taxa can be deemed to provide reasonable confidence in the absence of the chosen indicator species. In order to inform this process, it is advised to consult local experts on the ecology of the species. In this example, butterfly surveys conducted in at least three of the ten years prior to survey design was considered an appropriate level of survey effort to confirm presence or absence of the indicator species. Known absence data can be augmented by other sources of knowledge of absence from sites if deemed appropriate, i.e. site managers' knowledge and local expertise.

*d) Spatial resolution and producing working layers*

Define an appropriate and ecologically meaningful spatial resolution for data collection in the defined landscape and import a polygon layer of Ordnance Survey grid squares encompassing the extent of the target landscape. A 1 km cell size is considered widely applicable. Select grid squares using each of the potential range, known range, and known absence layers to create three new layers:

a. *Potential range:* only those grid squares suitable for occupancy or containing suitable habitat for the focal indicator species. Consider whether there is a minimum patch size that the indicator species can meaningfully occupy, and exclude squares containing only patches below this size threshold.

b. *Known range:* only those grid squares in which the indicator species has been recorded in the defined post-survey design timeframe.

c. *Known absence:* only those grid squares in which there are records (survey effort) for the target taxa in at last the minimum defined number of years in the pre-connectivity survey design timeframe to provide reasonable confidence in the absence of the chosen indicator.

*e) Spatial dispersal potential*

Informed by the dispersal ecology of the chosen indicator species, define a distance from occupied grid squares that the focal indicator species might be expected to disperse over. Buffer the *known range* grid square layer by this distance and use this to select from the *potential range* layer only those squares within the defined distance of occupied squares and exclude occupied squares to create a *dispersal buffer* layer.

*f) Creating the target survey location layer*

a) From the *potential range* layer, select and exclude all *known range* grid squares and save as a new layer 1,

b) From new layer 1, select and include only those grid squares also present in the *known absence* and save as a new layer 2,

c) From new layer 2 select only those squares also present in the dispersal *buffer layer* and save as a new layer 3. Layer 3 is the target survey locations layer and contains only grid squares in which patches suitable for occupancy by the focal indicator species exist, that are within dispersal distance from grid squares known to be occupied, and in which sufficient survey effort to provide reasonable confidence in the absence of the focal indicator species within an appropriate timeframe has been conducted. Finding the indicator species in these locations would provide reasonable evidence of colonisation facilitated by connected landscape[12].

*g) Temporal dispersal potential*

Prior to commencing survey effort, consider the timing of the start of survey effort post-connectivity improvement, and the duration of survey effort needed to detect colonisation of new patches over time, in light of temporal dispersal patterns of the focal indicator species.

[11] *https://cran.r-project.org/*
[12] *If on completing these steps few or no target survey locations remain, consider whether a) the indicator species chosen is too rare to be meaningful in the study landscape, b) the chosen spatial scale is appropriate.*





# OP6.5 Case study – testing a field survey approach to detect functional landscape connectivity using indicator species

The project applied and tested the Survey Site Selection Equation to the design of a field survey for two example taxa, one with a relatively fast dispersal ecology (a butterfly, Adonis blue) and one with a slower dispersal ecology (a reptile, adder), to test the approach with two levels of temporal dispersal potential.

**1. Defining landscape parameters.** The study area chosen was The North Kent Downs, to some extent a functionally delineated landscape in terms of the extent of chalk grassland habitat and the potential functional connectivity of chalk grassland specialist species. This is potentially more discrete for invertebrates than vertebrates, though in the case of reptiles, despite a general preference for a broad range of suitable habitat, adder exhibits a strong association with the chalk bedrock geology of Kent. Connectivity may be contiguous with patches outside of any defined study area, limiting the scope and relevance of any patterns detected to the extent of the area in question. If species can disperse into the study area from outside, the accuracy of the results around the periphery of the study area may be limited. By defining a study area delineated by a defined habitat extent in this way, it was possible as far as reasonably practical, to examine connectivity with the bounds of a functionally discrete landscape to a greater extent than feasible using an arbitrary project boundary.


Chalk grassland © Lucy Carden

**2. Defining the theme to be addressed:** functional connectivity; evidence that a landscape has improved in permeability to facilitate the dispersal of species.

**3. Articulating the objective, question or hypothesis:**

- H0: there is no evidence of the defined indicator species occupying previously unoccupied patches within the study landscape.
- H1: there is evidence of the defined indicator species occupying previously unoccupied patches within the study landscape.

### Specify the required data

The required data was specified as presence/absence of the focal indicator species in habitat patches at 1 $km^2$ resolution. The resolution was chosen based on the scale of the landscape. A more granular resolution (< 1 $km^2$ squares) would be unfeasible to resource in terms of survey effort at the scale of the focal landscape. A course-scale resolution (≥ 10 $km^2$ squares) would reduce the number of candidate target survey sites and the level of survey effort needed to confirm presence/absence of the indicator species, however, this would decrease the resolution of the data collected to a less informative scale.

A 1 $km^2$ resolution of survey sites offered a suitable compromise between resolution and survey effort and was chosen to provide a resource-to-scale effective approach. Furthermore, this resolution is commonly used in the UK, at a county scale, for species distribution reporting. Both taxa chosen to test the approach are well recorded to at least a 1 $km^2$ resolution in Kent.

JOINED
Background & rationale | Development | Audit & gap analysis | Practical approach | Limitations | Next steps | Synthesis & application

### 4. Attributes of monitoring programmes

Survey design for the two example indicator taxa considered the attributes from the **OP3.3 Ordered list of attributes of monitoring programmes**. This output presents a ranking of attributes of monitoring programmes in order from most elemental to most aspirational. The table details how the survey design considered and adopted these attributes.

| Attribute | | Butterfly | Reptile | Comment |
|---|---|---|---|---|
| Most elemental | Objectives and questions defined | ✓ | ✓ | From the outset the hypothesis was articulated. |
| | Standardised methods and protocols | ✓ | ✓ | County experts for the two indicator taxa were consulted on the most appropriate methods and protocol, and those chosen were established best practice. |
| | Suitable, accurate, efficient sampling methods | ✓ | ✓ | The methods chosen were deemed to be suitable, accurate, and efficient for recording the specified data required. |
| | Sufficient contributors | ✓ | ✓ | Volunteers were recruited to ensure there were sufficient contributors. |
| | Suitable and accessible identification resources | ✓ | ✓ | Training, ield guides and in-house materials for identification of species were provided to contributors. |
| | National, regional, or local coordination | ✓ | ✓ | Data collected was inputted into Recorder 6, provided to the Local Environmental Records Centre, and county recorders. |
| | Efficient data entry, storage and processing systems | ✓ | ✓ | Use of field recording forms, spreadsheets and Recorder 6 provided efficient data management. |
| | Data is reliable and validated | ✓ | ✓ | Contributors received bespoke training and guidance, clear direction to record photographs to validate identification provided, and data validated by county recorders as applicable. |
| | Results and findings fed back to participants | ✓ | ✓ | Results and findings were fed back to contributors at regular intervals during the project. |
| | Sufficient contribution of specialist knowledge | ✓ | ✓ | The respective county experts were consulted at various points during the survey design and implementation stages. |
| | Appropriate analytical and statistical approaches available | | | |
| | Good retention of contributors | ✓ | ✓ | Contributors were retained throughout the survey season. Unfortunately, we were unable to comment on their retention into 2020 due to COVID-19 implications. |
| | Mentoring, training and support for contributors | ✓ | ✓ | Species identification and survey method training sessions were provided by county experts to train new volunteers. |
| | Analytical and statistical approaches accessible | ✓ | ✓ | Appropriate techniques are widely accessible. |
| | Change reported at appropriate intervals | ✓ | ✓ | Change was reported at the end of the survey season. |
| | Appropriate, scientific, sampling design | ✓ | ✓ | The design for the survey was a scientific scheme design. |
| | Simple reporting of widespread and common species/attributes available to all | ✓ | ✓ | The simple survey design incorporated the recording of presences of the chosen species as well as other more common species that could be spotted in the same location. |
| | Results disseminated widely | ✓ | ✓ | Results and findings were fed back to volunteers, project stakeholders, Kent Wildlife Trust supporters and the general public at regular intervals during the project. |
| | Best practice shared between organisations and schemes | ✓ | | The best practice guidance for both species was used to design the survey method as well as consulting the retrospective county experts. Findings of the new approach was disseminated at the end of the project. |
| | Indicator/important species or attributes identified | ✓ | ✓ | Important indicator species were identified from both taxa groups taking into account local biodiversity plans and their conservation status. |
| | Wide coverage by participants | ✓ | ✓ | Participants undertook the survey across a landscape-scale area. |
| | Collection of supplementary data (i.e. habitat soil, weather) | | ✓ | The survey design for adder incorporated an additional habitat suitability index for Kent Reptile and Amphibian Group (KRAG) which assessed the quality of the habitat for reptiles. |
| | Focus on important species, locations, habitats etc. | ✓ | ✓ | The chosen species indicator taxa are both priority species for Kent and are included in the Kent Biodiversity Strategy[24]. The chalk grassland habitat is also of national importance and a priority habitat for Kent. |
| Most aspirational | Electronic data capture | | | All data was collected on paper forms in the field and then entered digitally by staff and volunteers. |
| | Change reported annually | | | We were unable to comment on annual change due to COVID-19 implications restricting a second survey season in 2020. |

[24] https://www.kentnature.org.uk/biodiversity-strategy.html


Nature's Sure Connected: A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.

**5. Selecting indicator species(s)**
See **OP6.3 Case study: a practical approach to modelling and quantifying landscape connectivity for species** using Circuitscape.

**6. Survey design**
The target survey sites within the landscape were identified using the *Survey Site Selection Equation* detailed previously. Figure 6.9 provides a conceptual diagram of the equation. The target survey locations were identified in QGIS as described below. The site selection method was similar for both Adonis blue and adder with differences as outlined.

## Adonis blue

1. The first step was to identify the *potential range* of Adonis blue. A layer was created that showed the mapped extent of chalk grassland within the defined landscape of the North Kent Downs. Chalk grassland coverage in Kent is variable and to ensure the *potential range* incorporated only habitat patches of a large enough size to be used by the indicator species, only habitat areas larger than one hectare were included. This choice of patch size reduced the chance of wasting resource surveying small patches of chalk grassland that would be unlikely to support Adonis blue.
2. The next step was to map the *known range* of Adonis blue. Species record data were obtained from Kent and Medway Biological Record Centre. A focal landscape area polygon was used to select only records within this defined geographic area. The temporal range of records was 1956-2018, and all records pre-2009 were excluded to ensure the recent species range was used. The resulting layer contained all the Adonis blue records in the focal landscape area between 2009 and 2018 as points.
3. The next step was to create a layer of the *known absence* of Adonis blue. Using the layer of all butterfly records in Kent, 1 km grid squares that did not contain any records of Adonis blue were selected based on survey effort. For each grid square, if butterfly records existed for three or more of the ten years preceding survey, none of which were of Adonis blue, the species was considered absent in that square. Records did not have to derive from consecutive years or taxa-specific surveys.
4. The *spatial resolution* chosen was 1 km as a suitable compromise between resolution and survey effort, providing a resource-to-scale effective approach. Each data source was converted to include all 1 km squares occupied by each data set. This was done by using a select function, for each of the *potential range, known range*, and *known absence* layers to create three new layers of 1 km grid squares. This created three layers of 1 km grid squares, each containing 1) >1 ha of chalk grassland, 2) Adonis blue records in three or more years, and 3) no Adonis blue records and at least 3 years of butterfly survey effort, respectively.
5. The next step was to define the *spatial and temporal dispersal potential* of the chosen indicator species, informed by the dispersal ecology of the focal indicator species. Butterfly Conservation were consulted to define a distance from occupied grid squares that the indicator species might be expected to disperse in one year, deemed to be up to 2 km. The *known range* 1 km grid square layer was buffered by this distance and used to select from the *potential range* layer only those squares within the defined dispersal distance. This created the *dispersal buffer* layer that contained those squares within 2 km of squares occupied by Adonis blue.
6. Next, from the *potential range* layer, all grid squares also present in the *known range* layer were excluded and those remaining saved as a new layer. From this layer, only those grid squares present in the *known absence* layer were selected and saved as a new layer. From this layer, only those squares present in the dispersal buffer layer were selected and saved as a new later. This is the final *target survey locations* layer containing only grid squares in which patches of habitat suitable for occupancy by Adonis blue exist, that are within dispersal distance from grid squares known to be occupied, and in which sufficient survey effort to confirm absence of Adonis blue within the 10 years prior to survey design can be reasonably assumed.
7. An additional step was to consider circumstantial features that may hinder the ability to access potential survey sites. Any 1 km grid squares for which landowner permission to survey chalk grassland could not be obtained were excluded. A total of 40 potentially suitable grid squares were identified, and landowner permission obtained for 26 of these.

## Adder

A similar approach was used to select reptile survey sites at 1 km resolution. Data were again obtained from the Kent and Medway Biological Record Centre, and additionally from Kent Reptile and Amphibian Group to define the *known range* of the species. The survey effort parameter was reduced to one year, based a greater survey effort requirement for reptiles, meaning fewer locations in which absence could reasonably be assumed were likely to be identified. The potential dispersal distance from occupied grid squares was again deemed to be 2 km. While closely associated with chalk grassland in Kent, adders may also occupy other habitats, therefore the selection of suitable habitat to create the *potential range* layer was augmented by visual inspection of satellite imagery to determine patch size and suitability for each 1 km grid square within 2 km of the *known range* layer. A total of 51 grid squares were identified within 2 km of the known range of adder which contained no records of the species, and for which there were one or more years of reptile records, providing reasonable confidence in absence. Of these, 34 contained suitable habitat (scrub, grassland, heathland), and of these, landowner permission to survey was obtained for 11.





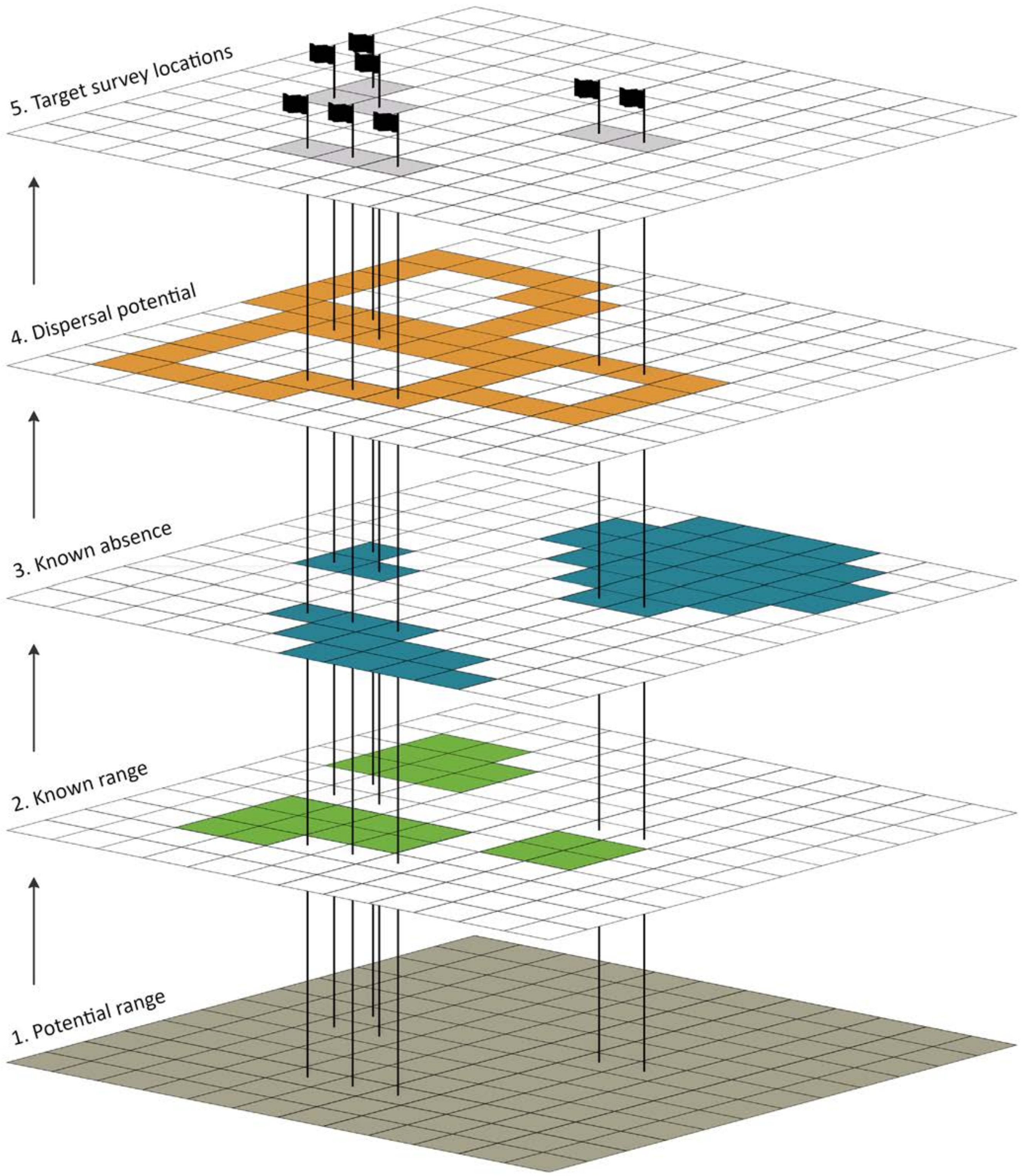


*Figure 6.10* **A conceptual diagram of the Survey Site Selection Equation.**

## 7. Survey method

### *Butterflies*

The field survey method was based on the UK Butterfly Monitoring Scheme timed count method[13]. Timed counts were chosen as they are particularly effective for monitoring rare habitat specialist butterfly species, especially those whose distribution fluctuates across large areas. Surveyors were allocated 1 km survey squares and were asked to spend at least an hour surveying per visit, at last once a week during the flight period(s) in suitable weather, and to walk at a slow steady pace to count butterflies. All sightings were recorded on a survey form, along with supplementary data (temperature, percentage sun, wind direction and speed) and collated in a central database. The standard recording forms were adapted to use a simple tally of counts and the list of butterflies limited to species present in Kent. Surveyors were provided with a site map, recording form, UK butterfly identification guide, and further identification guidance and recommendations for further reading. Surveyors were encouraged to use close focusing binoculars and to take photographs to aid identification and record verification.

### *Reptiles*

The reptile survey method was based on direct observation and refugia ('tinning') survey methods[14,15]. Surveyors were asked to complete the initial refugia survey setup visit early in the season, and then to return to the site to conduct a minimum of seven surveys between July and October. Ten suitable locations to place the refugia pairs (one felt & one metal) were chosen by the surveyor across the survey site. The refugia were left for two weeks to bed in before surveyors conducted their first surveys. Kent Reptile and Amphibian Group provided recording forms. Surveyors were provided with a survey site map, recording form, an adder habitat recording form and assessment manual and were encouraged to use close focusing binoculars and to take photographs to aid identification and record verification.

### *Survey volunteer recruitment*

The project provided an opportunity to develop new partnerships and marketing to support the recruitment of new landscape-scale ecology volunteers to test and resource the approach. Volunteer roles were advertised in partnership with Butterfly Conservation and Kent Reptile and Amphibian group and aimed to recruit people with an interest in wildlife, with no prior expertise required. A minimum time commitment of one survey a week was specified. Survey sites were selected by volunteers from the pool of sites selected using the Survey Site Selection Equation, to minimise the administrative burden and allow participants control over their level of involvement with the project. A total of 26 (butterfly) and 14 (reptile) volunteers conducted 132 and 101 hours of survey, respectively.

### *Surveyor training and support*

An aim of the project was to develop training to improve ecological knowledge and the sustainability of landscape-scale monitoring in Kent, and help create longer lasting, mutually beneficial volunteer engagement for all partners. In addition, confidence in data integrity was critical. Volunteers attended dedicated training sessions for each role to provide them with the skills and confidence to conduct surveys and identify target species. Three butterfly and two reptile training sessions were held, with support from Kent Reptile and Amphibian Group, at various locations in Kent on sites with suitable habitats and species. To enable butterflies to be observed in the hand, butterfly nets and bug pots were provided. The training covered:

- Project background and context,
- Focal taxa ecology, lifecycles, food plants, habitat management,
- Target species identification critical identification features, and confusion species,
- Survey methods and technique,
- Refugia placement (reptiles), effective use of butterfly nets and safe netting and potting of specimens (butterflies),
- Health and safety,
- A field excursion to practice identification.

### *Data processing and analysis*

Data was returned by participants in spreadsheets and was collated by project staff and volunteers. A further data volunteer role was advertised to assist the project team and further develop the volunteer skill base for mutual benefit of partners and volunteers. A total of 10 volunteers contributed to data processing. Data were stored in Recorder 6, and shared with the Local Environmental Records Centre, and county recorders validated the data collected.

## 8. Results

A total of 26 target survey location were surveyed for Adonis blue, and 11 for adder. Records of Adonis blue were received for seventeen locations (**Figure 6.11**), in which the Survey Site Selection Equation had established reasonable confidence in absence in the 10 years prior to survey. Records for three of these locations were accepted, while 14 failed verification by the county recorder (discussed in limitations) and these sites were noted for further surveillance. No adders were found in any of the target survey locations, though slow worm, viviparous lizard and grass snake were recorded (**Figure 6.12**). The most significant outcome of the survey the observation of Adonis blue in locations it had previously been considered absent, demonstrating that the species has now reached these sites and suggesting that sufficient connectivity exists to facilitate dispersal.

[13] https://www.ukbms.org/Downloads/UKBMS%20Ng1%20-%20Timed%20count%20guidance%20notes.pdf
[14] *Gent, A.H. & Gibson, S.D., eds. (2003) Herpetofauna Workers' Manual. Joint Nature Conservation Committee, Peterborough.* http://jncc.defra.gov.uk/page-3325
[15] *Froglife (1999) Reptile survey. An introduction to planning, conducting and interpreting surveys for snake and lizard conservation. Froglife Advice Sheet 10. Froglife, Halesworth.* http://www.devon.gov.uk/froglife_advice_sheet_10_-_reptile_surveys.pdf





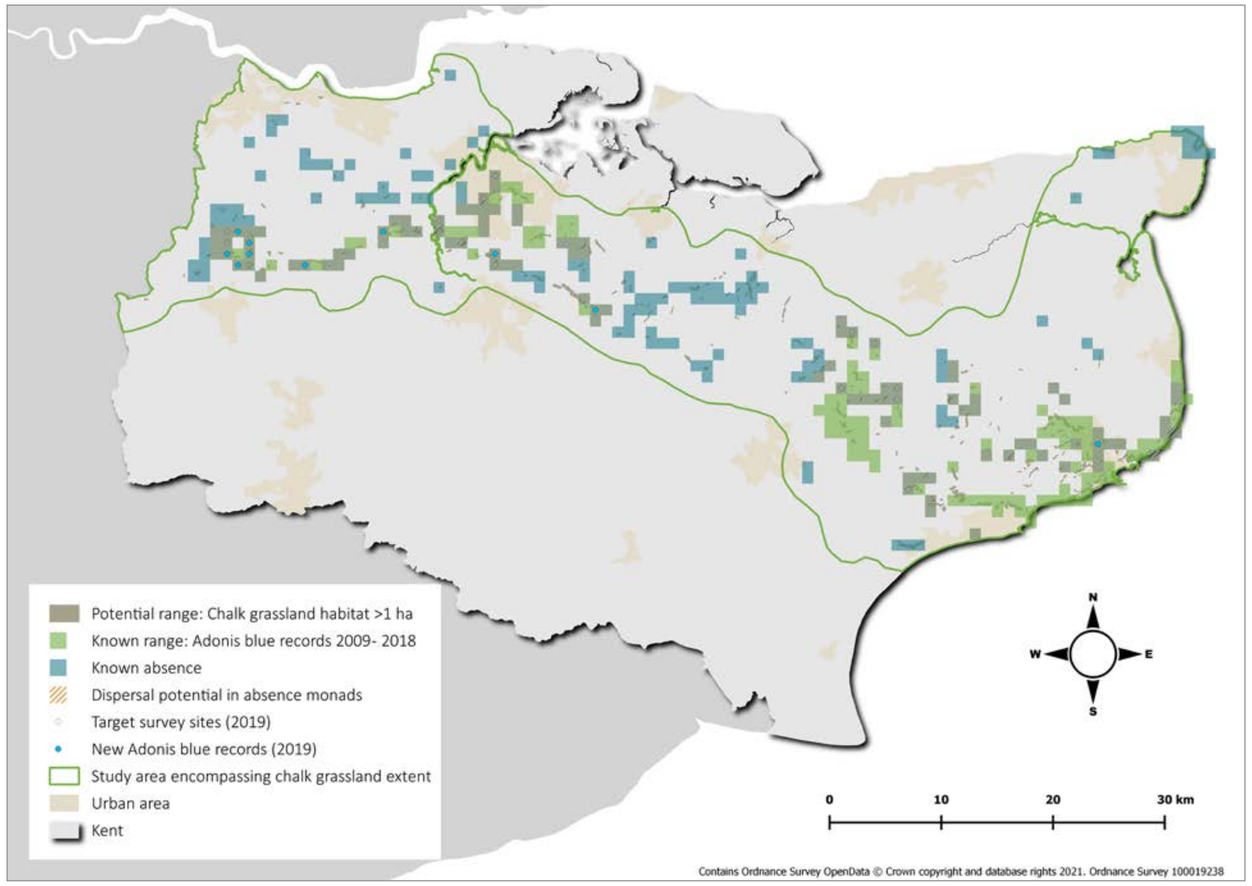


*Figure 6.11* **Map showing the results of the field survey approach to detect functional landscape connectivity for Adonis blue, including the components of the Survey Site Selection Equation.**

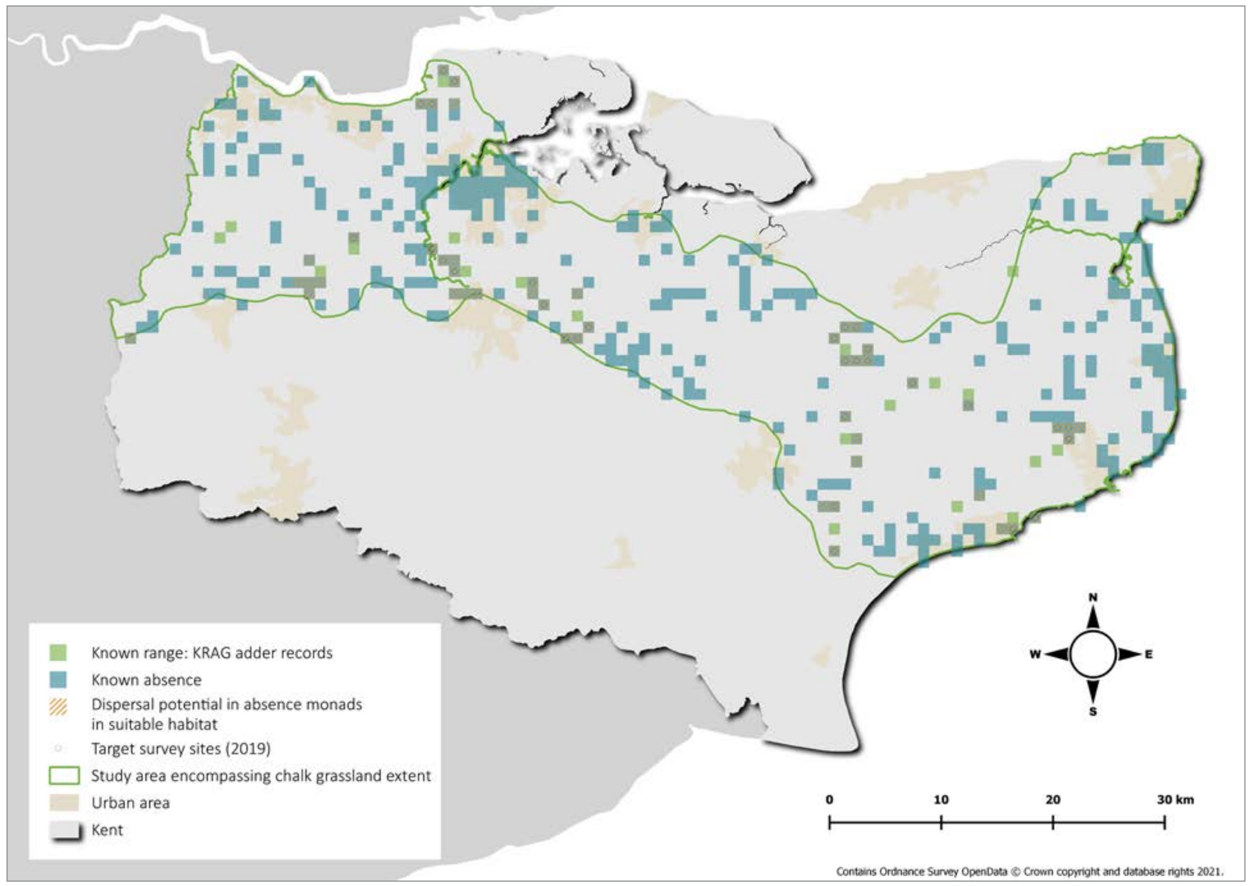


*Figure 6.12* **Map showing the results of the field survey approach to detect functional landscape connectivity for adder, including the components of the Survey Site Selection Equation.**

**9. Discussion**

By selecting species that fit the *Criteria for selecting landscape-scale indicators* (**OP3.7**) and applying the Survey Site Selection Equation the survey approach developed by the project detected occupation of new habitat patches:

- That were of suitable habitat type for the species,
- For which a degree of confidence in prior absence had been established using current distribution and survey effort data, and,
- Within the anticipated dispersal distance from occupied patches.

Having reached previously unoccupied patches we infer that habitat connectivity exists for Adonis blue. Although not all Adonis blue records were accepted by county verifiers due to the locations lacking any former records within the last ten years, locations that warrant further surveillance that might enable the detection of functional connectivity were identified. While no new patches occupied by adder were found, this was anticipated to a certain extent on the basis of the slow dispersal rate of this species. Surveys conducted by the project have established greater confidence in the baseline absence data for adder at these sites however, and have again identified areas that warrant future surveillance and the potential to detect functional connectivity in future.

# Limitations

The COVID-19 pandemic and the three subsequent government sanctioned lockdowns within the timeframe of the project restricted project ambition with respect to progressing the link between connectivity modelling and the validation of models with field survey data. Furthermore, ambition with respect to the further development of the field survey approach was curtained by the inability to carry out second field season. Nonetheless, useful progress was made in developing knowledge of analytical techniques to quantify theoretical connectivity and in developing and testing a field survey approach to detect functional connectivity.

### Connectivity modelling

- The most significant limitation on the validity of model outputs arose from the disparity in the resolution of mapped habitat data between 2003 and 2012 surveys, which probably accounts for significant variation in connectivity observed between these points in time. To resolve this issue, modelling should be repeated using consistently mapped habitat data.
- Circuitscape does not inherently require input of the known range of the focal species, which leads to a disconnect between the predicted core areas for the species, and the population distribution predicted by habitat permeability. **This was addressed by using cores based on species distribution data and indigenous expert knowledge.**

### Field survey

- The most significant limitations of the approach were in a) the criteria used for record verification for county recording and b) a low number of photographic records of suspected Adonis blue specimens. Previous records of a species in a location are one of the criteria for accepting new records of critical species, and not all records received by the project were supported by photos. Verification was considered critical, and consequently this combination led to only three of a potential 17 new locations for Adonis blue being considered reliable indicators of connectivity, though it may the case that a larger number can be verified in future.
- While the approach provided the reasonable confidence in absence of the focal indicator species prior to survey necessary to allow functional connectivity to be detected, it is recognised that it cannot be an entirely reliable indicator of absence. However, by adopting the Survey Site Selection Equation approach, sites in which dispersal within a connected landscape in which new instance of colonisation are most likely to be detected can be identified, in which a concerted effort to establish prior absence can be targeted efficiently. Once absence is more reliably established, these locations can then be ongoingly monitored to detect new colonisation, in locations where the likelihood of detection can be reasonably confidently anticipated.
- It was recognised that evidence of completing the life cycle in a location is a more meaningful indictor of a species presence than occupancy alone, and it was an aspiration of the project to incorporate this into the approach in a second survey season. This was curtained by the impact of the COVID-19 pandemic and is considered in next steps and recommendation below.

Ant hills in chalk grassland. Ants are essential to life cycle of the Adonis blue butterfly © Guy Edwardes 2020Vision

# Next steps and recommendation

### Connectivity modelling

- Recently, the UK Centre for Ecology and Hydrology (UKCEH) have made available consistent and regularly updated land use data, which may offer the opportunity for more robust comparison of connectivity than the existing Kent habitat survey data allows. To assess the method described here using consistently mapped data it is proposed to repeat the modelling process again using the UKCEH Land Cover Maps[16], which includes 20m resolution raster layers of habitat type. This provides far more consistently resolved habitat mapping from which interpretation of variation in connectivity can be more confidently made.
- To account for the disconnect between Circuitscape predicted cores and the actual species distribution of focal species, it is recommended that cores based on local expert knowledge of the most important sites for focal species are used to generate greater certainty in model outputs.

### Field survey

- The novel field approach to assessing functional connectivity presented here will benefit from being trialled and developed more widely within the conservation community, and others are encouraged to adopt and feedback on its implementation.
- Confidence in the results obtained from this approach can be enhanced by adopting it for long-term monitoring to first identify locations where the likelihood of detection can be reasonably confidently anticipated and establishing robust absence data in the early years of the programme. While existing occupancy may become apparent on some sites, a smaller subset may then provide the opportunity for functional connectivity to be detected. Conservation organisations could adopt the Survey Site Selection Equation as part of wider monitoring activities to test its usefulness for monitoring functional connectivity for species within landscapes.
- Where occupation of new sites by a species can be established, the subsequent re-application of the Survey Site Selection Equation to the design of subsequent surveys, using an updated known range layer including these new records, provides a mechanism to monitor further evidence of functional connectivity beyond the current distribution of a focal indicator species.
- Greater emphasis on and encouragement of volunteers to examine and photograph specimens in the field, and an awareness of a need to place less weight on previous records of a species (where other verification criteria are robust) will facilitate confidence in the validity of a greater proportion of records that have the potential to indicate functional connectivity for focal species, particularly those for which confusion species exist (I.e., Adonis blue and common blue butterflies).
- To enhance how meaningfully occupancy data can indicate functional connectivity, gathering data to evidence a focal indicator species completing stage its lifecycle within sites is considered desirable. This would provide greater confidence in the detection of viable populations establishing. It is proposed that a next step in the development of the approach should be to incorporate food plants and sub-adult stages of life cycles into surveys of target survey locations identified using the Survey Site Selection Equation.
- The development of a field survey app. using a platfom such as Mergin[17], which allow a custom recording form to be set up with automated storage in a geospatial database, will of substantial benefit to the approach.

# Synthesis and application

The continued use of connectivity modelling approaches, coupled with the use of a novel field survey approach, offers a starting point for conservation organisations to design and carry out landscape-scale field surveys of connectivity which go beyond simply modelling the potential, theoretical, likelihood of landscapes providing enhanced connectivity as a result of conservation action. Validating such models with field survey data will improve their subsequent use and application, enhancing the strength of evidence for and further improvement of the effectiveness of landscape-scale conservation action.

[16] https://www.ceh.ac.uk/ukceh-land-cover-maps
[17] https://public.cloudmergin.com/



Chapter 7: BIODIVERSITY

Hovering kestrel © Luke Massey 2020Vision

# Background and rationale

**Metrics of biodiversity are key to our understanding of the outcomes of landscape-scale conservation, and practitioners and policy makers increasingly require robust trend data at a variety of spatial scales. Nationally, this need is well-served by a variety of well-established monitoring and recording schemes. These schemes may be structured, for example, Breeding Bird Survey, Wetland Bird Survey, Avian Demographics Scheme[1], Seabird Monitoring Programme, National Bat Monitoring Programme, UK Butterfly Monitoring Scheme, National Plant Monitoring Scheme, or unstructured, for example, Rare Breeding Birds Panel, species recording schemes, and opportunistic recording.**

These programmes are designed to contribute to the overall surveillance and monitoring needs within the UK. They achieve this by supporting efficient schemes that meet multiple requirements and support uses at UK, country and, in some cases, local scales. The programmes invest with partners in long-term schemes, most of which depend on a huge contribution of time and effort by skilled volunteers. Schemes are sufficiently widespread and systematic to allow for assessment of trends in distribution and/or populations at national scale. Although the schemes are taxonomically based, in many cases their sampling strategies are designed to make them sensitive to the environmental and anthropogenic drivers of change operating at broad scales. Through analysis, they can provide information relevant to a wide range of policies.

A frequent suggestion by the stakeholders consulted in the development of this framework was that extracting county and landscape-scale data from national data sets might provide a solution to the assessment of trends to evidence and inform sub-national scale policy and practice. There remains a challenge in the widespread practical application of this approach. National datasets do not consistently provide sufficient sampling effort, replication and statistical power for the assessment of trends at smaller scales. Recent advances in statistical techniques combining structured and unstructured survey data offer potential solutions, though accessibility need to be improved for routine practical application by ecologists and non-academic organisations.

The project adopted a dual approach to tackling this challenge, by attempting to develop a practical approach to monitoring species populations at landscape-scale, and by reviewing recent advances in statistical techniques to understand and provide stakeholders with an up-to-date picture of the potential application of national-scale data to landscape and county-scale biodiversity trend assessment.

Linnet © Jon Hawkins, Surrey Hills Photography

[1] *Combines the Nest Record Scheme and the National Ringing Scheme to obtain data on population size, breeding success and survival rates of birds.*





# Development

| | |
|---|---|
| **1. Stakeholder contribution** | How stakeholders informed the design of the approach:<br>• Prioritised biodiversity trend assessment as a key theme in landscape-scale monitoring.<br>• Expressed a desire to investigate the application of national monitoring scheme data to biodiversity trend assessment at landscape-scale.<br>• Expressed a desire for landscape-scale monitoring to encompass the 70% of UK landcover that is used for agriculture. |
| **2. Audit and analysis** | The project reviewed a range of existing biodiversity monitoring schemes and considered their potential application to assessing species trends at landscape-scales.<br><br>Audit and analysis resulted in:<br><br>• *OP7.1* **Comparative assessment of biodiversity monitoring schemes.** |
| **3. Development and testing** | **Principles**<br>The following principles were recognised and adopted in development and testing, informed by the outcomes of the stakeholder consultation and audit and analysis phases:<br><br>• Resourcing of structured surveys at county and sub-county-scales is typically out of scope of organisations working at landscape-scale.<br>• Abundance-occupancy relationship: the relationship between the local abundance of species and the size of their ranges within a region. A positive, inter- and intraspecific, abundance–occupancy relationship is a widespread feature of ecological assemblages. The larger the population size, the greater its distribution.<br><br>**Practical approach**<br>Guided by the above principles, the project adopted an abundance-occupancy approach to the design of a field survey methodology to investigate trends in biodiversity at landscape-scale in a farmed landscape.<br><br>• A farmed landscape was selected as the study area to support landscape-scale work by Kent Wildlife Trust to facilitate a Farmer Cluster in the catchment of the Upper Beult River in Kent.<br>• A survey methodology was developed based on the principle of species distribution mapping.<br>• Suitable indicator species were selected.<br>• Farmers were consulted and invited to participate.<br>• Volunteers were recruited, trained and supported to conduct the surveys.<br>• Training and identification guidance to support the survey was produced.<br>• A case study was produced to inform stakeholders. |
| **4. Outputs** | • *OP7.2* **Case study: Monitoring farmland bird distribution in the Upper Beult Farmer Cluster.**<br>• *OP7.3:* **A review of recent advances in the application of national datasets to the assessment of landscape-scale trends.** |

# Audit and gap analysis

## OP7.1 Comparative assessment of biodiversity monitoring schemes

| Example schemes and surveys[1] (Not exhaustive) | Advantages | Disadvantages |
|---|---|---|
| **Biological recording schemes (unstructured)**<br>• Botanical Society of Britain and Ireland<br>• British Mycological Society<br>• British Bryological Society<br>• National Amphibian & Reptile Recording Scheme<br>• British Dragonfly Monitoring Scheme<br>• Freshwater Fish Recording Scheme<br>• Aquatic Coleoptera Recording Scheme<br>• Ground Beetle Recording Scheme<br>• UK Ladybird Survey<br>• Scarabaeoidea Recording Scheme<br>• Hoverfly Recording Scheme<br>• National Earthworm Recording Scheme<br>• Sealife Survey | The historical legacy of biological recording in Britain and Ireland is unique and inspiring.<br><br>Many naturalists are committed to studying UK flora and fauna, and the Biological Record Centre and Local Environmental Record Centres help to ensure that the value of observations is maximised.<br><br>The vast datasets built up through the expertise and commitment of the volunteer recording community enables a range of ecological questions to be addressed.<br><br>Distribution trends derived from the large-scale and long-term datasets provide evidence for many purposes, particularly in relation to understanding environmental change.<br><br>Distribution trends can be produced at national and sub-national scales, for example national and county-scale species atlases.<br><br>Recording is often supported through the use of mobile apps. They make it easier for more people to participate. By using GPS, camera, clock, and mobile network, resulting records are more accurate. | Biological recording often lacks strategic direction in the design of sampling to allow production of trends at sub-county and landscape-scales.<br><br>Not resourced adequately to provide sufficient coverage at sub-county/ landscape scales.<br><br>Insufficient data to generate trends at sub-county/landscape scales.<br><br>Un-structured approach to sampling means that while spatial distribution trends can be measured, it is far more difficult to measure population change. |
| **Structured monitoring schemes**<br>• Breeding Bird Survey<br>• Goose and Swan Monitoring Programme<br>• Wetland Bird Survey<br>• UK Butterfly Monitoring Scheme<br>• National Plant Monitoring Scheme<br>• National Pollinator Monitoring Scheme | Many naturalists are committed to contributing to structured monitoring schemes.<br><br>Vast data sets enable a wide range of ecological metrics to be assessed, including population trends.<br><br>Population trends derived from the large-scale and long-term datasets provide evidence for many purposes, particularly in relation to understanding environmental change.<br><br>Population trends can be produced at national scales.<br><br>Monitoring is supported through established, structured, survey methodologies and schemes. | Not resourced adequately to provide sufficient coverage at county and sub-county/landscape scales.<br><br>Insufficient data to generate trends at county and sub-county/landscape scales.<br><br>Advanced statistical techniques that enable both structured and unstructured survey data (i.e. Biological Recording Schemes, ad hoc records) to be combined to enable trend assessment at sub-national scales are typically out of reach of non-academic organisations. |

1 https://www.brc.ac.uk/recording-schemes





# Practical approach

## OP7.2 **Case study:** Monitoring farmland bird distribution in the Upper Beult Farmer Cluster

### Background and rationale

Species occupancy or distribution mapping is commonly used to determine species coverage and is widely applied in conservation practice at both national[2,3], and county-scale[4,5]. Atlases are important for biological recording while also providing a basis for periodic review of the distribution of species within a taxonomic group. Atlas datasets are often used for research, and now cover over 10,000 species of plants and animals in the UK. Many atlases are richly detailed reference works which include much more than just distribution data. Atlases and their associated datasets have revealed major changes in species' ranges over the past 50 years and are being used to address a growing number of research questions. Maps, species accounts and associated information within atlases are also increasingly used to make informative and attractive websites to support recording.

The application of distribution mapping at site-scales[6] and to attributes of habitat condition[7] is increasingly being adopted by practitioners. Complete coverage can be achieved by scaling sampling resolution to resource availability, and spatially referenced data overcome some of the issues associated with other approaches. However, the spatial resolution of species atlases and therefore resulting model predictions are often too coarse for local applications[8]. Collecting distribution data at a finer resolution for large numbers of species often requires a comprehensive sampling effort, making it impractical and expensive.

### The occupancy-abundance relationship

The occupancy–abundance (O–A) relationship is the relationship between the abundance of species and the size of their ranges within a region. This relationship is one of the most well-documented relationships in macroecology and applies both intra- and interspecifically (within and between species). The abundance and distribution of species tend to be linked, such that species declining in abundance tend to show declines in the number of sites they occupy, while species increasing in abundance tend to increase in occupancy. Therefore, intraspecific abundance–occupancy relationships are commonly positive, and often accompanied by positive interspecific abundance-occupancy relationships, such that widespread species tend to be abundant, and narrowly distributed species rare[9].

The O-A relationship has important implications for the monitoring and conservation of species, however not all occupancy-abundance relationships are positive, and in such instances the underlying mechanisms remain poorly understood. For example, to what extent can a species remain widespread but in reduced numbers before this change is detected in occupancy? Theoretically, it would be possible over 100 1 km squares, for a species to have 100% occupancy with 100,000, or 10,000, or a minimum of 100 individuals, before a change in occupancy is detected. A recent study focused on the average change across invertebrate, bryophyte and lichen species, showed that while average occupancy among most groups in the UK appears to have been stable or increasing, there have been substantial changes in population sizes[10]. Occupancy trends underestimate abundance trends. For example, when assessing trends in both the occupancy and the abundance of butterflies in the Netherlands, van Strien et al[11] observed larger variation in average abundance than in average occupancy, while both measures suggested an overall negative trend. It must be recognised that occupancy monitoring still requires substantial survey time and resources, but it is considerably more efficient than structured surveys of abundance when deployed at the landscape scale. Thus, given the frequent lack of capacity to resource abundance surveys at a landscape-scale, we considered the O-A relationship a robust basis on which to design a survey approach.

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11 van Strien, A.J., van Swaay, C.A.M., van Strien-van Liempt, W.T.F.H., Poot, M.J.M. & WallisDeVries, M.F. (2019) Over a century of data reveal more than 80% decline in butterflies in the Netherlands. Biological Conservation, 234, 116–122

## Context

Approximately 70% of the UK is under some form of agricultural management and to ensure these habitats are well managed and associated species declines are reversed farmers and landowners who rely on these landscapes for their income must be engaged. Land devoted to agriculture consists of arable land and pastures, as well as semi-natural habitats such as hedgerows and field margins that provide food and shelter for birds. Amongst the public and conservation organisation there is concern over the decline in farmland bird numbers; in 2019 the England farmland bird index was 42% of its 1970 value[12]. Even more alarming is the decline in species are now farmland specialists; turtle dove, tree sparrow, grey partridge, corn bunting and starling populations are at 20% of their 1970 levels. Currently, as an organisation, we don't have a way of monitoring these populations at the landscape-scale in Kent.

There is a growing recognition that collaborative working in a geographic area can achieve more than working in isolation. Farmer clusters are increasingly being facilitated by conservation organisations as a collaborative means to achieve landscape-scale conservation outcomes and mutual goals. Kent Wildlife Trust have been instrumental in setting up and promoting new farmer clusters across Kent. These cluster groups help farmers and land managers to work together to deliver more for wildlife and the environment than one individual could achieve alone.

A series of workshops were convened by the project at which collectively, 60 conservation practitioners representing 37 organisations discussed and established the five landscape approaches. Discussion around the question '*Are species distributions increasing?*' frequently turned to addressing the lack of evidencing of conservation outcomes in farmed landscapes.

In order to address stakeholders' suggestions, and the challenges of monitoring large tracts of agricultural land, the focal landscape chosen for this approach was a farmed landscape in Kent which was largely encompassed by the Upper Beult Farmer Cluster (UBFC). The UBFC was established in 2019, in partnership with Southern Water. A Farmer Cluster Officer works directly with farmers in the Upper Beult catchment via the establishment of a long-term Farmer Cluster to help farms protect and improve water quality, soil health and biodiversity. The cluster group was in its early stages of development when we presented them with our practical approach to assessing species abundance using occupancy. This allowed us to consult with the cluster members to determine whether our approach was achievable and how much support they could provide.

Corn bunting © David Tipling 2020Vision

[12] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/938272/England_Wild_Birds_1970-2019_final_.pdf





## Survey design

The project sought to develop a practical approach to assessing species abundance using occupancy as a means of overcoming the challenge of resourcing sufficient structured survey effort of abundance at landscape-scale to generate robust trend analyses. Development of the approach was informed by the steps defined in **Chapter 3**:

| 1. Define landscape parameters | 2. Define theme to be addressed | 3. Articulate objective, question or hypothesis | 4. Specify required data | 5. Attributes of monitoring programme | 6. Selecting indicator(s) | 7. Develop practical approach |
|---|---|---|---|---|---|---|

**1. Define landscape parameters:** the study landscape was defined as the extent of the project area of the Upper Beult Farmer Cluster shown in Figure 7.1

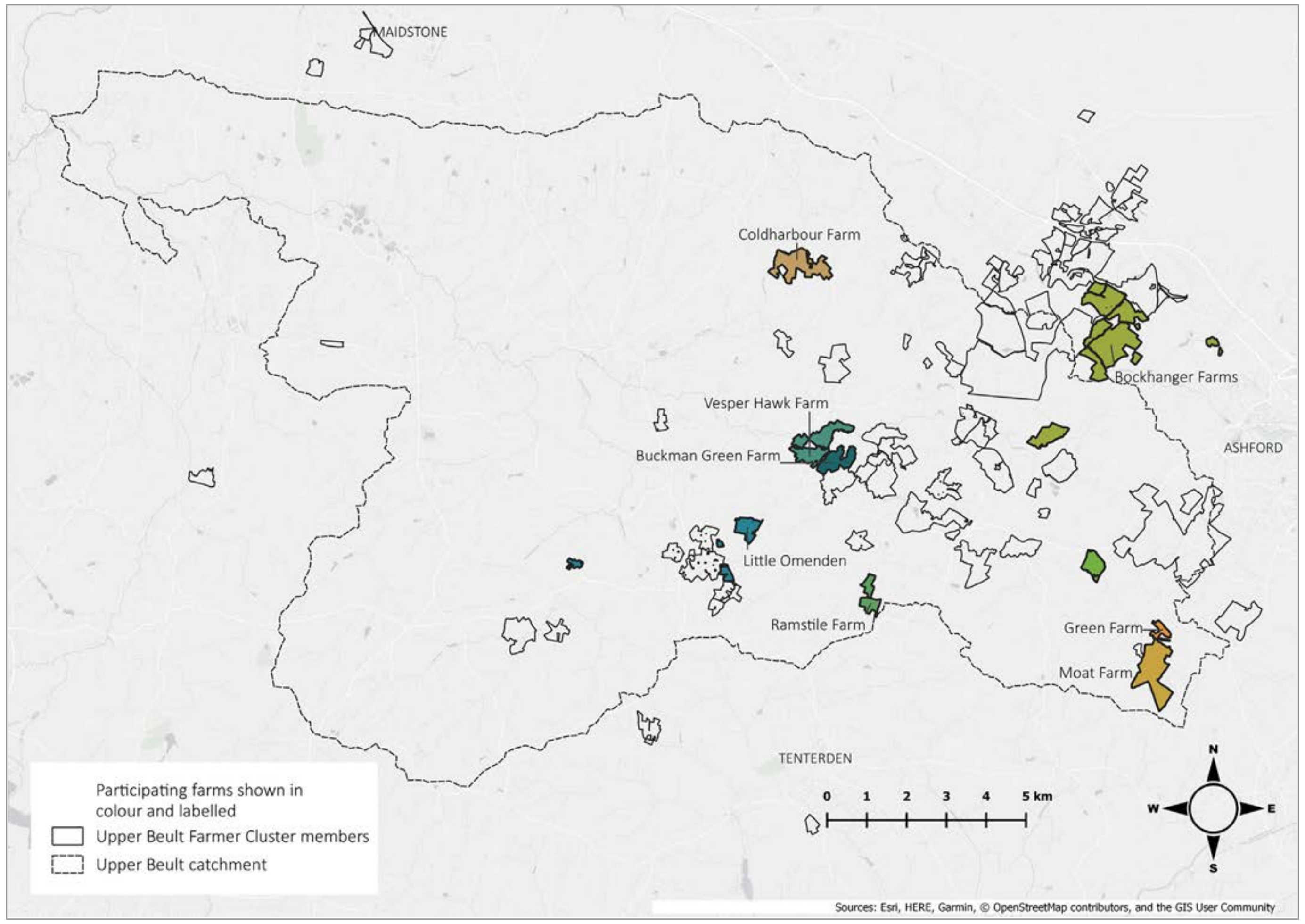



*Figure 7.1* **Upper Beult Farmer Cluster: Farms included in survey approach, Kent.**

**2. Define theme to be addressed:** trends in species occupancy, and by proxy, abundance.

**3. Articulate objective, question or hypothesis:** the objective of this approach was to determine trends in species occupancy and abundance for key species, and whether this has changed as a result of conservation effort. It is important to articulate the specific objective, question or hypothesis. An example of a null and alternative hypothesis might be:

- H0: there is no evidence of variation in species occupancy within the study landscape.
- H1: there is evidence of variation in species occupancy within the study landscape.

Recognising that the UBFC was in its infancy and had patchy membership in the early stages of its development, the primary objective was to test the application of the approach, rather than to achieve a comprehensive survey of the entire landscape. Additional objectives included supporting the development of relationships with cluster members, developing expertise in monitoring on land outside of the organisations reserve network, and to explore opportunities for further partnership working.

Fallow deer © Gillian Day

## Data requirements

**Occupancy**
Presence/absence of target species occupying patches of habitat at a defined spatial resolution within the focal landscape.

**Spatial resolution**
Most species distribution atlases map distributions in the form of a grid overlaid on the area covered, each cell of which is filled in some way to indicate presence, abundance or breeding status. Globally, spatial resolution of atlases (measured as the area of an atlas grid square) can vary enormously, with grid square size varying between 0.06 km$^2$ and 14 400 km$^2$ [13]. In the UK, distribution mapping is typically carried out at 10 km$^2$ (national[14]) and 1 km$^2$ (county) scales. There remains a technical challenge for practitioners in determining appropriate scales of resolution for sub-county scale distribution mapping.

Here a 1 km$^2$ resolution was chosen to facilitate a resource-to-scale effective approach, though it is accepted that this may be too course to provide detailed resolution at sub-county landscape-scales. Individual studies should consider an appropriate resolution for the requirements of study landscapes and within resource constraints.

[13] *David W. Gibbons, Paul F. Donald, Hans-Günther Bauer, Lorenzo Fornasari & Ian K. Dawson (2007) Mapping avian distributions: the evolution of bird atlases, Bird Study, 54:3, 324-334, DOI: 10.1080/00063650709461492*
[14] https://www.brc.ac.uk/atlases





### 4. Attributes of monitoring programme

The survey design for the approach considered the desirable attributes of monitoring programmes. **See OP3.3 Ordered list of attributes of monitoring programmes**. This output displays the ranking of attributes of a monitoring programme in order of importance from most elemental to most aspirational. The table below sets out the how the survey design met the attributes.

| Attribute | | Comment |
|---|---|---|
| Most elemental | Objectives and questions defined | From the outset the hypothesis was articulated. |
| | Standardised methods and protocols | Standard survey methods and protocols for surveying the selected indicator species are well established and were chosen as applicable. |
| | Suitable, accurate, efficient sampling methods | The survey methods chosen were deemed to be suitable, accurate, and efficient for recording the specified data required. |
| | Sufficient contributors | Volunteers and landowners within the focal landscape area were recruited to ensure there were sufficient contributors. |
| | Suitable and accessible identification resources | Field guides and in-house materials for identification of species were provided to contributors. |
| | National, regional, or local coordination | The survey was co-ordinated at the focal landscape scale, and data provided to the Local Environmental Records Centre. |
| | Efficient data entry, storage and processing systems | Use of field recording forms, spreadsheets and Recorder 6 provided an efficient data management solution. |
| | Data is reliable and validated | Contributors received bespoke training and guidance, clear direction to record photographs to validate identification provided, and data was validated by the project team. |
| | Results and findings fed back to participants | Results and findings were fed back to contributors and landowners at regular intervals during the project. |
| | Sufficient contribution of specialist knowledge | Survey approach and design was informed by peer reviewed scientific literature, and by local expertise. |
| | Appropriate analytical and statistical approaches available | Analytical techniques for species occupancy modelling are well established. The need to develop and incorporate validation and calibration of occupancy with sub-sampling of abundance metrics is recognised and discussed in the review and recommendations section of this chapter. |
| | Good retention of contributors | There was good retention of contributors throughout the pilot survey season. Longer term survey would need to consider a retention and succession strategy. |
| | Mentoring, training and support for contributors | Species identification and survey method training sessions were provided to volunteers by project staff. |
| | Analytical and statistical approaches accessible | At the most basic level, distribution maps are easily assimilated by non-specialist audiences. |
| | Change reported at appropriate intervals | The approach developed would allow change to be reported at appropriate intervals. |
| | Appropriate, scientific, sampling design | Species occupancy mapping is an appropriate approach to survey design for the intended purpose. |
| | Simple reporting of widespread and common species/attributes available to all | At the most basic level, distribution maps are easily assimilated by non-specialist audiences and provide a format for simple reporting. |
| | Results disseminated widely | Results and findings were fed back contributors, landowners, and to project stakeholders. In future application results can be disseminated more widely. |
| | Best practice shared between organisations and schemes | The approach developed here is shared with relevant stakeholders through this framework. |
| | Indicator/important species or attributes identified | Key indicator species were identified in the context of the focal landscape. |
| | Wide coverage by participants | Participants undertook the survey across a landscape-scale area. Coverage achieved in this pilot development approach was not fully comprehensive, though the approach provides a sustainable model. |
| | Collection of supplementary data (i.e. habitat soil, weather) | Not applicable. |
| | Focus on important species, locations, habitats etc. | This approach focused on the farmed landscape which is a key landscape in Kent and the UK. The survey also had a focus on the important species and habitats associated with a farmed landscape. |
| | Electronic data capture | All data was collected on paper forms in the field and then entered digitally by staff and volunteers. Electronic data capture solutions are feasible, though were out of scope in this development stage. |
| Most aspirational | Change reported annually | The approach developed would allow change to be reported annually if annual survey were desirable and resourced. The appropriateness of annual versus long-term trend reporting should be considered. |

**5.Selecting indicator species(s):** The decision on what to monitor to detect landscape-scale outcomes can be a daunting and challenging task. The production of criteria for selecting landscape-scale indicators created consensus across the conservation community and for comparison of landscape-scale studies in the future. The project criteria for selecting landscape-scale indicators were developed through stakeholder consultation and encourage contemplation on whether the species chosen is suitable as an indicator for the landscape-scale question addressed. The criteria can be used in conjunction with information on the ecology of candidate indicator species and expert knowledge, to select suitable indicator species (see OP3.7 Criteria for selecting landscape scale indicators).

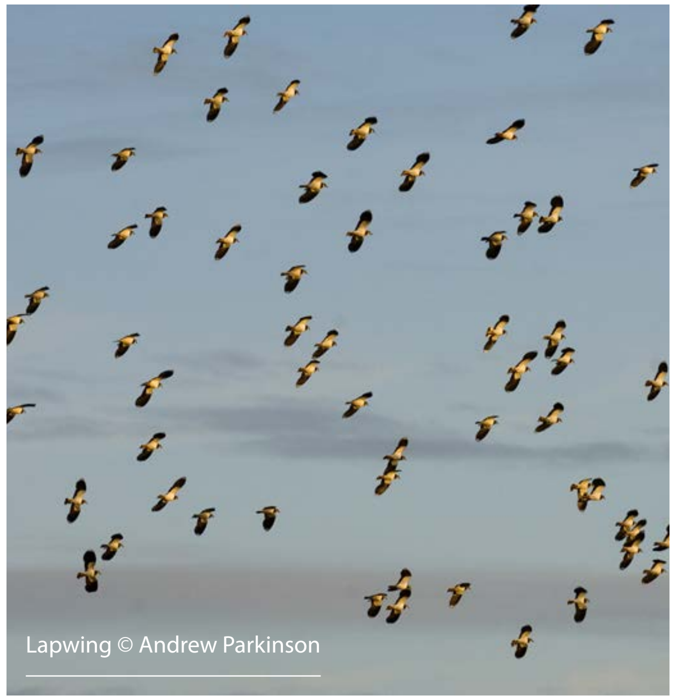
## Birds

The Farmland Bird Indicator[13] formed the basis of indicator species selection. The British Trust for Ornithology (BTO) categorise all common breeding birds in Britain and Ireland by the habitats on which they are dependent. Species which commonly occupy more than one habitat fall in a generalist category. The farmland category consists of 'species feeding in open farmland during the breeding season, even though they may nest in woods and hedges' and includes 28 species. Six of these are too rare to be monitored by general survey methods, and two are introduced species and were excluded. One (the barn owl) is nocturnal and is therefore also not well monitored by general methods. When the Farmland Bird Indicator was devised in 1999, Defra chose to use the remaining 19 species, for which annual population trends can be estimated, to calculate an annual average index. Indicator species selection was augmented by: 1) consideration of Birds of Conservation Concern 4[14], 2) in light of wetland management objectives within the focal landscape, selection of species that rely on riparian habitats, and 3) consultation with local experts through the project technical advisory group. Monitoring of all species likely to be encountered was considered, but rejected to reduce the risk of novice, volunteer surveyors being overwhelmed. Inclusion of some common, generalist species was designed to promote surveyor enthusiasm and motivation, rather than focusing only on less common species likely to be encountered infrequently.

### Survey season

Often more birds are present on farmland in winter than in summer. This is because birds aggregate into large flocks in the winter, which are more noticeable than when they are scattered across the farmland during the breeding season. Also, many species move to Britain from northern Europe to avoid the harsher winter weather on the continent. Numbers seen on farmland in the winter are therefore very variable, often more a reflection on breeding success outside of the UK. Breeding population counts are a much more reliable means of monitoring population changes in response to landscape-scale management in the UK.

The objective of the project was to develop an approach to monitoring the occupancy of farmland birds in the breeding season and including mammals, plants and insects. In light of the COVID-19 pandemic, it was not possible to conduct surveys during the breeding, flowering and flight seasons within the project timeframe. Given that the purpose of the project was to design and test an approach, it was recognised that there was value in testing and developing all elements of the approach except for appropriate survey timing, with a view to practical application during the bird breeding season. Migrant bird species, plants and insects were therefore excluded from the list of target indicator species.



Lapwing © Andrew Parkinson



[13] Department for Environment, Food and Rural Affairs, UK (2020). UK Biodiversity Indicators 2020.
[14] https://britishbirds.co.uk/wp-content/uploads/2014/07/BoCC4.pdf





## Mammals

Mammals of conservation concern were the starting point for the indicator species selection. The first official Red List for British Mammals was produced in 2020 by the Mammal Society and classifies all UK mammals into seven Red List categories[15]. Each mammal that was classified in the top four categories was considered for inclusion in the survey. Most species in these categories were not present in Kent and/or the focal landscape lacked habitat attributes needed by the species. To determine whether the chosen mammal species were present in the focal landscape distribution maps available in the Kent mammal atlas[16] were consulted. Indicator species selection also took into consideration the catchment management objectives within the focal landscape and therefore, mammals that rely on riparian habitats were also included. These were the water vole and European otter. We also included the brown hare which is commonly recorded alongside bird populations in the farmland landscape; for instance, in the English Winter Bird Survey (EWBS). Species that were not included due to lack of easily identifiable tracks or signs were the mustelids: weasel, stoat and polecat, along with various small rodents: harvest mouse, wood mouse, common shrew, water shrew, field vole and bank vole. Badger, European fox and European mole were also excluded. The inclusion of several large, charismatic mammals helped to promote surveyor enthusiasm and motivation. Target bird and mammal species surveyed are detailed in **Table 7.1**.

Brown hare © Jim Higham

[15] Mathews F, and Harrower C. (2020). IUCN – compliant Red List for Britain's Terrestrial Mammals. Assessment by the Mammal Society under contract to Natural England, Natural Resources Wales and Scottish Natural Heritage. Natural England, Peterborough ISBN 978-1-78354-485-1
[16] Young, J., Ryan, H., Thompson, S., Newcombe, M. & Puckett, J. (2013) Mammals of Kent. Kent Field Club.

Great crested grebe © Andrew Parkinson 2020Vision

Table 7.1 **Target bird and mammal species surveyed in the Upper Beult Farmer Cluster, Kent.**

| Birds | Mammals |
|---|---|
| Kestrel | Water vole |
| Grey partridge | Hare |
| Yellowhammer | Otter |
| Skylark | Red deer |
| Corn bunting | Sika deer |
| Reed bunting | Fallow deer |
| Linnet | Roe deer |
| Greenfinch | Reeve's muntjac deer |
| Goldfinch | |
| Tree sparrow | |
| Starling | |
| Lapwing | |
| Rook | |
| Jackdaw | |
| Stock dove | |
| Wood pigeon | |
| Great crested grebe | |
| Little grebe | |
| Moorhen | |
| Grey heron | |
| Redwing | |
| Fieldfare | |



BIODIVERSITY
Background & rationale | Development | Audit & gap analysis | Practical approach | Alternative approaches | Limitations | Next steps | Synthesis & application

## 6. Survey Design

Survey design focused on maximising accessibility to novice surveyors, scientific rigour, co-design and partnership. A key objective was to test the approach of engaging landowners and testing the feasibility of training novices to collect useful data. Regular consultation with landowners ensured they were kept informed and involved. The project technical advisory group provided expertise to inform development, and a single facilitator was able to build repour with the stakeholder group.

*Consultation, co-design and partnership working*

From the outset, the survey was designed collaboratively between the project team, the Kent Wildlife Trust Farmer Cluster Officer for the UBFC, Southern Water, and farmers. A partnership agreement was established, and all organisations took responsibility for providing guidance, feedback and promoting the survey. The team attended Farmer Cluster meetings to engage farmers and landowners about the wildlife on their farms, biological recoding and the proposed survey approach. Members were asked to complete a short digital survey on the wildlife on their land and their biological recording activity.

Just under 30% of farmers regularly recorded wildlife on their farms, typically as paper records, photography or making a mental note. The most common reason for not recording wildlife was a lack of time, resources, or lack of confidence in identifying wildlife. Farmers identified a wide range of wildlife present on their land and outlined a range of species they would like to benefit. The results of the survey helped inform the development of our approach, which was presented to members for comment. They were asked to consider the inclusion of their farm in the survey, desire to undertake surveys themselves, and willingness to allow volunteers to conduct surveys on their land. A total of 13 farmers expressed a desire to be involved in the survey. Of these, two thirds were willing to conduct the surveys, with the remaining third willing to grant access to volunteer surveyors. Farmers provided details of site-specific access restrictions and health and safety considerations. They were also consulted on their confidence in identification of the target indicator species, and this informed the development of training resources.

*Surveyor recruitment*

A total of 15 surveyors included both members of the farmer cluster and volunteers. Through consultation it was established that some farmers were willing to conduct surveys, and others required volunteer surveyors. Frequently conservation organisations rely on volunteers for ecological surveys. The collaborative approach developed here provided the opportunity to build new partnerships and marketing to support the recruitment of new volunteers, including representatives from the agricultural community. Reducing reliance on the recruitment of volunteers from a pool in which there is increasing competition for citizen scientists, by engaging farmers in surveys, has the potential to enhance the sustainability of monitoring, fostering engagement and developing the knowledge and expertise of private landowners.

The Farmland Wildlife Surveyor role was advertised through various internal and external marketing channels and to species recording groups. The role advertised for people with an interest in wildlife, a friendly and approachable manner, and outlined no prior expertise of the surveys was needed. Clear expectations of time commitment were provided. A project mailing list was used as the main form of communication.

*Development of survey resources & guidance*

To minimise the amount of survey materials needed in the field, data recording forms and transect maps were combined in one document. A map of the survey transect with space for notes was displayed on one side whilst the other side displayed the target indicator species list recording form. These were produced at A3 size to maximise the number of visits recorded per form. A photographic species identification document was created, outlining the main identification features of each species, confusion species, and links additional resources. Surveyors were provided with a data recording spreadsheet and asked to transcribe field data to facilitate electronic submission and processing. All documents were distributed as paper hard copies or electronically, according to preference.

*Surveyor training and support*

A key aim of the approach was to develop training to improve skills and knowledge, to enhance the sustainability of monitoring at organisational and landscape-scales, creating longer lasting, mutually beneficial engagement. In addition, it was critical to establish confidence in the data collected. Volunteers were required to attend survey and species identification sessions. These were led by the project team and included an indoor presentation and an outdoor field walk. Further guidance on species identification was provided to volunteers after attendance at the training. Volunteers were also encouraged to contact project staff with photographs and queries as they arose whilst completing surveys.

## 7. Survey Method

*Method choice*

A variety of established survey methods were considered. For birds this included tetrad transect surveys following the BTO/JNCC/RSPB Breeding Bird Survey, the Common Bird Census territory mapping approach, point counts, casual recording, the English Winter Farmland Bird Survey, the Big Garden Birdwatch, and the Game and Wildlife Trust Big Farmland Bird Count.

To successfully record mammals the established survey approaches consist of two broad field techniques: live trapping methods or observational methods which encompass camera trapping, identification of tracks and signs or direct observation[17]. Established survey methods considered included the Mammal Society's Mammal Mapper phone app, the Mammal Society's Walk this Water Way survey, BTO/Mammal Society Winter Mammal Monitoring pilot study and BTO/JNCC/RSPB Breeding Bird Survey mammal recording.

A transect-based survey method was adopted based on a 1 km square resolution, with the route designed to encompass the range of habitats found in each square, and within the constraint of following field edges to avoid trampling winter crops. Surveyors aimed to conduct one survey visit to each square per week from November 2020 to February 2021. Surveys were conducted any time between dawn and dusk and only carried out in good weather. Typically, the surveyor met on-site with a member of the project team or landowner to familiarise themselves with the route and receive a health and safety briefing.

Surveyors walked the transect noting down presence or absences of the target species within the relevant 1 km square. Surveyors were encouraged to note an estimate of the total number of individuals of each species, though this was not considered essential for an occupancy mapping exercise, and this flexibility made the survey more accessible to novice surveyors.

*Data collation*

Data was returned by participants in spreadsheets and collated by staff. No new external software was purchased to complete the survey or data processing elements of this approach.

*Data validation*

It was recognised that building reliable species identification expertise is not always achievable in a short space of time. It can often take an individual a number of seasons of surveying to be able to reliably identify birds, for example. Resourcing landscape-scale monitoring presents challenges however, and there is often a shortfall of volunteer expertise, or resourcing to recruit experience for monitoring at sub-national scales. In recognition of these challenges, the approach developed here attempted to provide a compromise between reliability of data and resourcing survey effort. A three-step verification process was adopted. A concise target species list, training, and identifying likely confusion species was the first step in maximising accuracy. All data were subject to secondary verification by suitably experienced project staff, and lastly, data were submitted to the relevant county recorder for verification. Due to project timeframe constraints the data presented here passed steps one and two, and analysis will only be considered robust once step three has been completed.

[17] *Hoffmann, Anke & Decher, Jan & Rovero, Francesco & Voigt, Christian & Schaer, Juliane. (2010). Field Methods and Techniques for Monitoring Mammals.*



BIODIVERSITY
Background & rationale | Development | Audit & gap analysis | Practical approach | Alternative approaches | Limitations | Next steps | Synthesis & application

## 8. Results

A total of eighteen 1 km squares were surveyed within the Upper Beult Farm Cluster landscape. Twenty of a possible 22 species of bird were recorded, and three of a possible eight species of mammals. Results are presented in Figures 7.2 to 7.4.

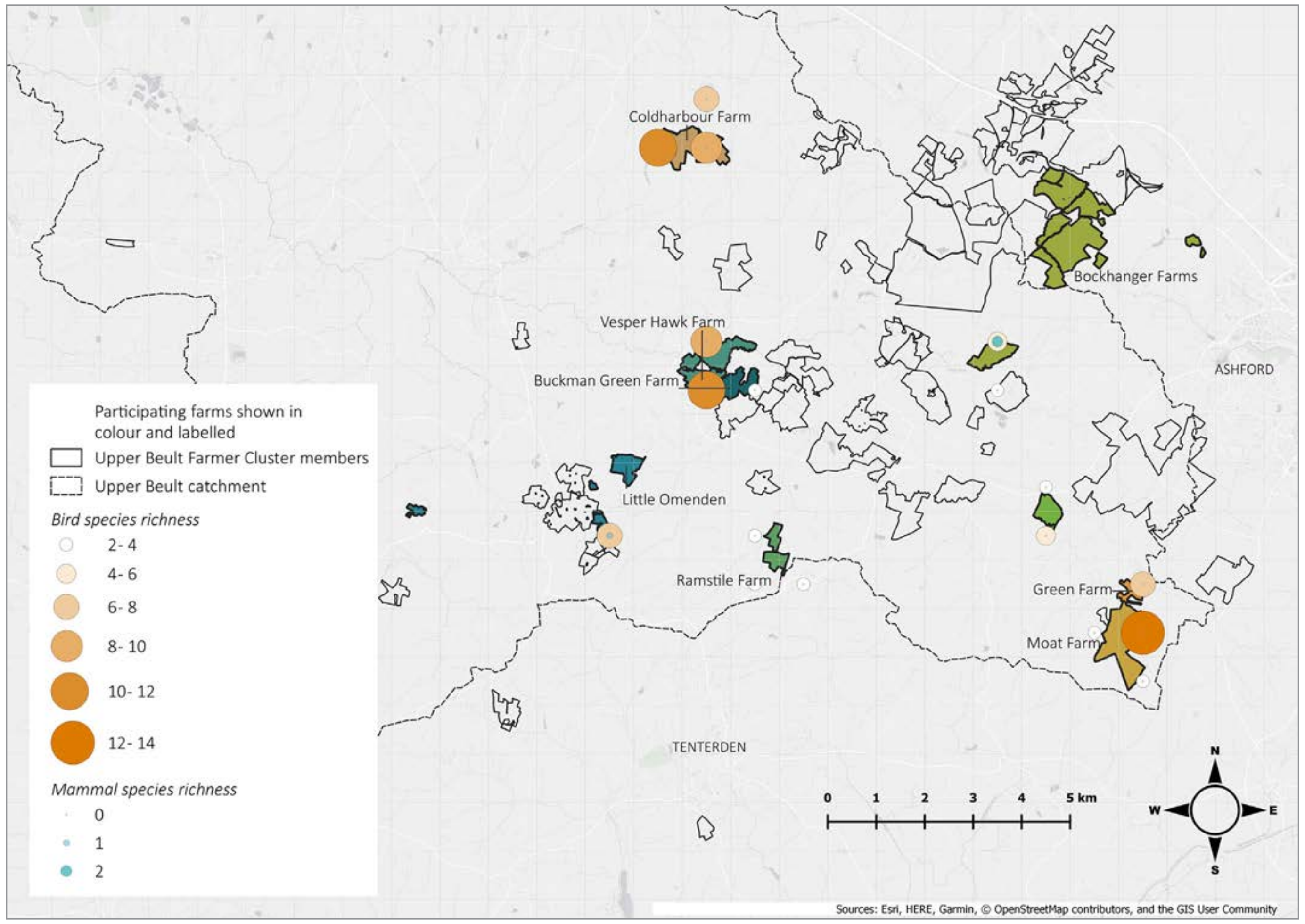



*Figure 7.2* **Species richness of target bird and mammal species recorded in the Upper Beult Farm Cluster landscape in 2020-2021.**

Goldfinch © Gillian Day

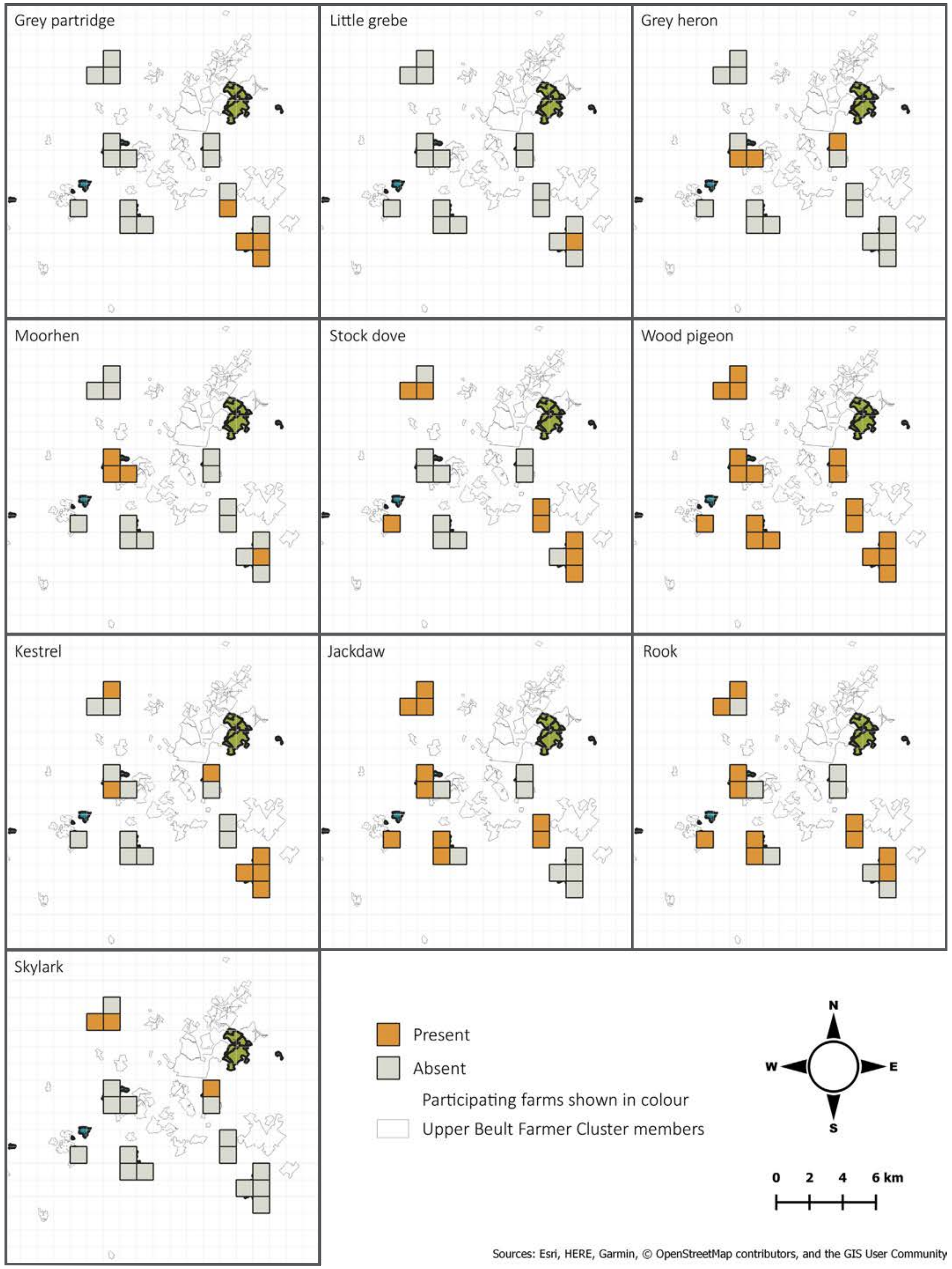



*Figure 7.3a* **One-kilometre distribution of target bird species observed in surveys of participating farms in the Upper Beult Farmer Cluster, Kent, between November and January 2020/21.**





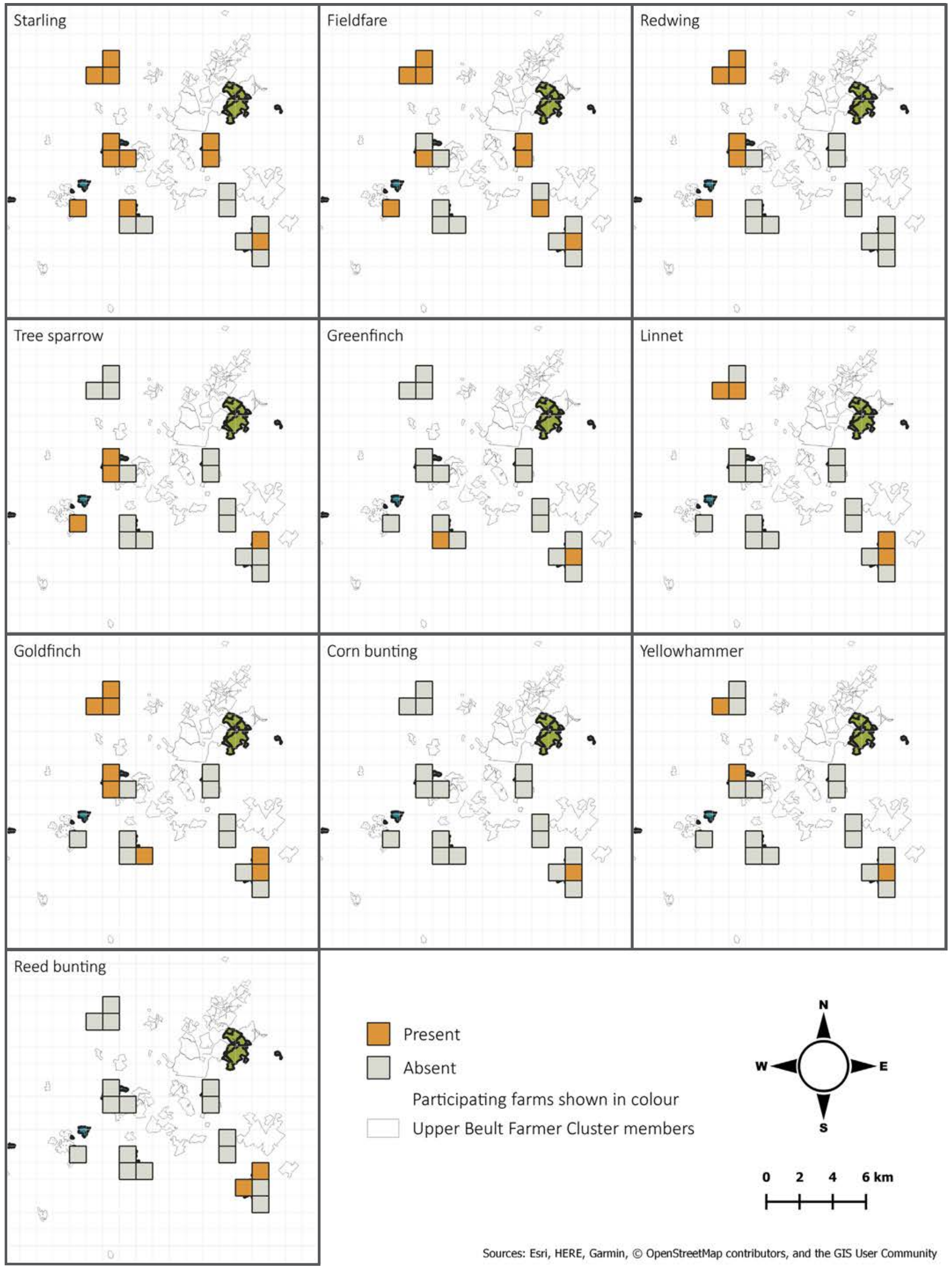



*Figure 7.3b* **One-kilometre distribution of target bird species observed in surveys of participating farms in the Upper Beult Farmer Cluster, Kent, between November and January 2020/21.**

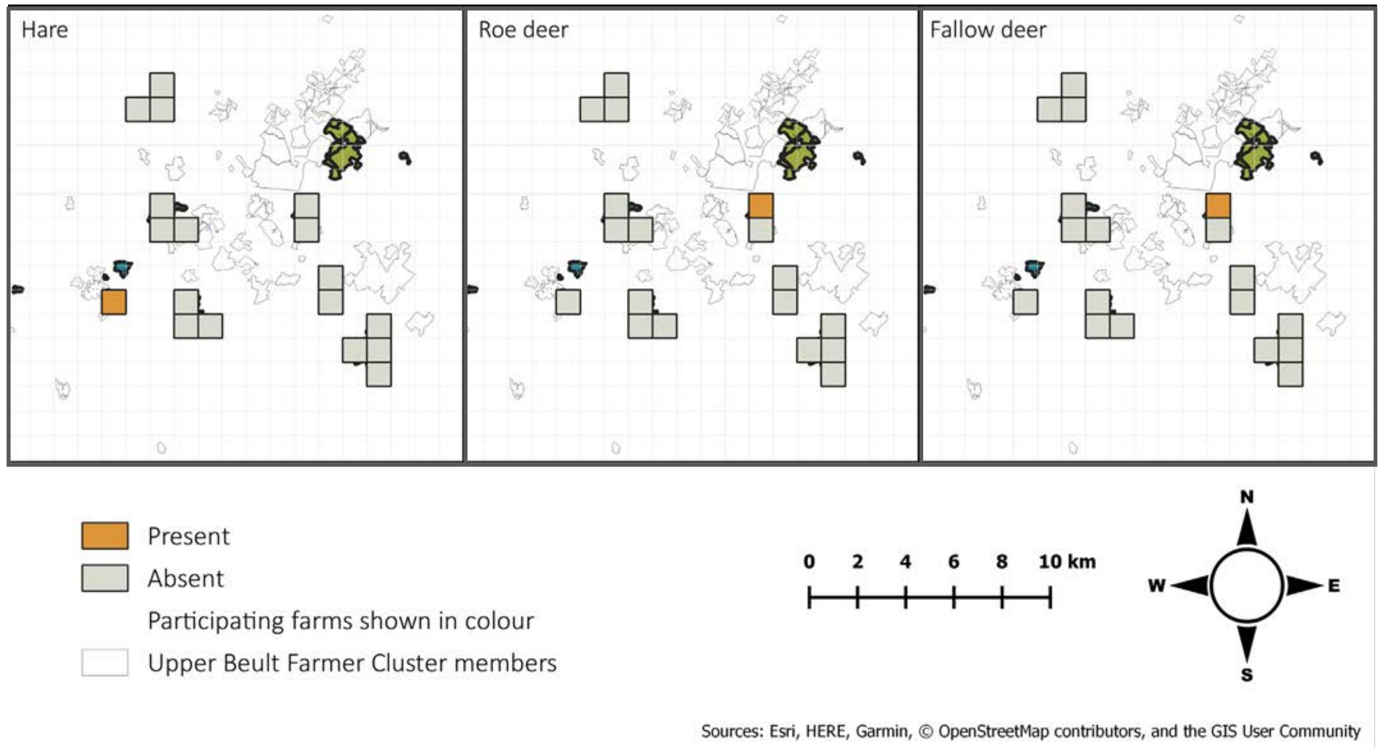



*Figure 7.4* **One-kilometre distribution of target mammal species observed in surveys of participating farms in the Upper Beult Farmer Cluster, Kent, between November and January 2020/21.**

Fieldfare © Richard Steele 2020Vision





# Alternative approaches

## OP7.3 A review of recent advances in the application of national datasets to the assessment of biodiversity trends

Biological recording is a very simple concept in which a record is the report of a species at a physical location at a certain time. National biological recording schemes provide some of the best available data for assessing trends in biodiversity at national scales. A frequent question put forward by project stakeholders was whether national data sets could be used for regional and/or landscape scale assessments of population trends. Upon investigation, it appears that such approaches have not been developed by practitioners due to a number of limitations and challenges. Whilst long-term national monitoring schemes generate high-quality, structured data, frequently on an annual basis, they are often taxonomically and geographically restricted, or data is collected at insufficient resolution or in insufficient quantity to be useful at sub-national scales.

Taking the example of breeding birds, one of the most extensively monitored groups nationally, the BTO advise that county-scale species trend assessment is reliable for species that occupy at least 30 Breeding Bird Survey (BBS) squares per year, averaged over the time series, and adjusted for declining species that started with at least 30 occupied squares. The project carried out a simple analysis of bird species occupancy in BBS squares in Kent between 1994 and 2019[18] (**Table 7.2**). Of 172 species for which BBS data exists for Kent, just 41 (24%) of species had sufficient occupancy to merit reliable trend analysis at county-scale. As might be expected, these were typically common species of least conservation concern (with some notable exceptions) and most are not frequently the target of conservation intervention. Furthermore, few have the ecological characteristics that meet the criteria for selecting landscape-scale indicator species developed by the project.

*Table 7.2* **Species recorded in breeding bird surveys in Kent between 1994 and 2019 with sufficient (>30 BBS squares) and insufficient (<30 BBS squares) occupancy in Breeding Bird Survey squares to permit reliable trend assessment at county-scale.**

| >30 BBS squares | <30 BBS squares |
|---|---|
| Woodpigeon, Turtle Dove, Collared Dove, Moorhen, Herring Gull, Great Spotted Woodpecker, Green Woodpecker, Jay, Magpie, Jackdaw, Rook, Carrion Crow, Blue Tit, Great Tit, Skylark, Swallow, Long-tailed Tit, Willow Warbler, Chiffchaff, Blackcap Whitethroat, Wren, Starling, Blackbird, Song Thrush, Mistle Thrush, Robin, House Sparrow, Dunnock, Pied Wagtail, Chaffinch, Greenfinch, Linnet, Goldfinch, Yellowhammer. | Helmeted Guineafowl, Red-legged Partridge, Grey Partridge, Quail, Peafowl, Brent Goose, Canada Goose, Barnacle Goose, Bar-headed Goose, Greylag Goose, Feral/hybrid Goose, Black Swan, Mute Swan, Egyptian Goose, Shelduck, Mandarin, Garganey, Shoveler, Gadwall, Wigeon, Feral/hybrid mallard type, Teal, Pochard, Tufted Duck, Goosander, Ruddy Duck, Nightjar, Rock Dove, Feral Pigeon, Water Rail, Coot, Little Grebe, Great Crested Grebe, Oystercatcher, Avocet, Lapwing, Golden Plover, Grey Plover, Ringed Plover, Little Ringed Plover, Whimbrel, Curlew, Bar-tailed Godwit, Black-tailed Godwit, Turnstone, Knot, Ruff, Sanderling, Dunlin, Woodcock, Snipe, Common Sandpiper, Green Sandpiper, Redshank, Spotted Redshank, Greenshank, Black-headed Gull, Mediterranean Gull, Common Gull, Great Black-backed Gull, Lesser Black-backed Gull, Sandwich Tern, Little Tern, Common Tern, Black Tern, Red-throated Diver, Fulmar, Gannet, Cormorant, Grey Heron, Little Egret, Sparrowhawk, Marsh Harrier, Hen Harrier, Buzzard, Barn Owl, Tawny Owl, Little Owl, Long-eared Owl, Short-eared Owl, Kingfisher, Lesser Spotted Woodpecker, Kestrel, Merlin, Hobby, Peregrine, Alexandrine Parakeet, Ring-necked Parakeet, Raven, Coal Tit, Marsh Tit, Willow Tit, Bearded Tit, Sand Martin, House Martin, Cettis Warbler, Wood Warbler, Sedge Warbler, Reed Warbler, Grasshopper Warbler, Garden Warbler, Lesser Whitethroat, Firecrest, Goldcrest, Nuthatch, Treecreeper, Ring Ouzel, Fieldfare, Redwing, Spotted Flycatcher, Nightingale, Black Redstart, Redstart, Whinchat, Stonechat, Wheatear, Tree Sparrow, Yellow Wagtail, Grey Wagtail, Meadow Pipit, Tree Pipit, Rock Pipit, Brambling, Hawfinch, Bullfinch, Twite, Lesser Redpoll, Crossbill, Siskin, Corn Bunting, Reed Bunting. |

Another promising data source is opportunistic or 'random' biological records, which are typically unstructured and inherently spatially and temporally biased, yet generate data in large volumes, even at local scales. These datasets, such as those collected through citizen-science mobile applications, hold great potential for addressing large-scale questions about biodiversity change. Records may be collected by citizen scientists at times and places that suit them, but this can lead to inherent sapling bias. Sampling biases may be spatial; when observers are more likely to record data at specific locations usually due to accessibility, or temporal, as research interests change over time or due to weather conditions. These need to be controlled for during the statistical analysis of the data. Furthermore, the data are often 'presence-only', and lack information on the sampling protocol or intensity, and thus pseudo absence locations must be generated which can lead to uncertainty in predictions.

Submitting 'complete lists' of all the species observed is one potential solution because the data can be treated as 'presence–absence' and the detectability of each species can be statistically modelled. In general, use of unstructured citizen-science datasets is limited amongst conservation practitioners, due to the scarcity of analytical methods, software and tools, in addition to the challenges associated with reducing inherent sampling biases. Here we provide an overview of recent advances in the use of structured and unstructured data and the practical application of analytical techniques to measure species trends with the aim of informing the conservation practitioner community of the scope and opportunities presented by these approaches for the monitoring of landscape-scale outcomes (**Table 7.3**).

Moorhen © Bertie Gregory 2020Vision

[24] *Pagel, J., Anderson, B.J., O'Hara, R.B., Cramer, W., Fox, R., Jeltsch, F., et al. (2014) Quantifying range-wide variation in population trends from local abundance surveys and widespread opportunistic occurrence records. Methods in Ecology and Evolution, 5, 751–760.*
[25] *Isaac, N. J., van Strien, A.J., August, T. A., de Zeeuw, M. P., & Roy, D. (2014) Statistics for citizen science: extracting signals of change from noisy ecological data. Methods in Ecology and Evolution. doi: 10.1111/2041-210X.12254*
[26] *Woodcock, B. A., Isaac, N. J. B., Bullock, J. M., Roy, D. B., Garthwaite, D. G., Crowe, A., & Pywell, R. F. (2016). Impacts of neonicotinoid use on long-term population changes in wild bees in England. Nature Communications, 7, 12459*
[27] *Powney, G.D., Carvell, C., Edwards, M., Morris, R.K.A., Roy, H.E., Woodcock, B.A. & Isaac, N.J.B. (2019) Widespread losses of pollinating insects in Britain. Nature Communications, 10.*
[28] *Outhwaite, C.L., Gregory, R.D., Chandler, R.E., Collen, B. & Isaac, N.J.B. (2020) Complex long-term biodiversity change among invertebrates, bryophytes and lichens. Nature Ecology & Evolution, 4, 384–392. Nature Publishing Group.*
[29] *Isaac, N.J.B., Jarzyna, M.A., Keil, P., Dambly, L.I., Boersch-Supan, P.H., Browning, E., et al. (2020) Data Integration for Large-Scale Models of Species Distributions. Trends in Ecology & Evolution, 35, 56-7.*
[30] *Simmonds, E.G., Jarvis, S.G., Henrys, P.A., Isaac, N.J.B. & O'Hara, R.B. (2020) Is more data always better? A simulation study of benefits and limitations of integrated distribution models. Ecography, 43, 1413–1422.*





*Table 7.3* **Overview of recent advances in the use of structured and unstructured data and the practical application of analytical techniques to measure species trends**

| Approach/method | Description | Strengths | Weaknesses | Technical requirements |
|---|---|---|---|---|
| Hierarchical model of abundance variation (authors applied the method to estimate abundance dynamics across the range of a butterfly species *Pyronia tithonus* in Great Britain between 1985 and 2004)[24] | Integrates observations from multiple sources (e.g. gridded annual population densities, long-term count data, opportunistic records, closed-population counts, capture-mark-recapture data) in a hierarchical modelling framework to estimate gridded population densities over a given period. | • Integrated quantitative approach gives more details on spatial patterns of abundance than existing qualitative approaches.<br>• Model could be extended to assign occurrence records to habitat type classes to account for survey bias.<br>• Moderate number of sites may suffice to infer a relationship between abundance and detectability. | • Intra-annual population dynamics are not accounted for.<br>• Does not account for spatial bias introduced by survey site selection process.<br>• Many repeated visits per grid cell for a substantial portion of the study area are desirable. | High: No programming code appears to be provided. |
| Dynamic Bayesian occupancy-detection model (BOD) (applied to assess change in the occurrence of 62 wild bee species in England over an 18-year period[25], tested against 10 other modelling methods[26], used to estimate trends in pollinating insects in the UK[27], and used to analyse trends in the UK distributions of over 5000 species of invertebrates, bryophytes and lichens[28]). | Occupancy (presence/absence) of each grid cell is separated statistically from the data collection process (detection), which makes BOD models well-suited to modelling change using opportunistic, unstructured data. | • Models are robust to multiple sources of error and bias.<br>• Model can incorporate covariates to test hypotheses about the drivers of biodiversity change.<br>• Model is dynamic, meaning persistence and colonization is modelled explicitly.<br>• Can be applied to multiple species simultaneously (multispecies models). | • The model is not wholly unaffected by all forms of variation in recorder activity.<br>• Data-poor species which may affect model convergence are excluded.<br>• Estimates of persistence must be imputed for years with missing survey data, resulting in smoothed estimates of occupancy.<br>• Intense targeted surveys or strong temporal bias in survey effort may lead to biased occupancy estimates.<br>• Computationally costly. | Medium: Detailed explanation of methods and programming code provided. |
| Point-process integrated models[29,30]. | True distribution is modelled for each data source as a point process, where intensity (points per area) varies as a function of environmental variables. The fitted model integrates all datasets to produce a single distribution map accounting for variation and bias in sampling effort. | • Not based on discrete space (grids), and therefore better-suited to datasets which differ in spatial coverage within a grid cell.<br>• Eliminates a priori assumption of suitable grid size. | • Computationally costly if Bayesian implementation.<br>• One must assess the value of combining datasets, based on factors such as sample size, biases, unknowns surrounding collection methods.<br>• Integrated model may not outperform a model using a single data source, based on evaluation/error metrics. | Medium-high: Code provided for basic implementation, but methodological guidance is fairly limited. |
| Species distribution models (SDM) | Species distribution models estimate relationships between species locations and environmental variables to project the geographical space over which species occur with an associated scale of suitability. | • Extensive body of literature and software for implementation.<br>• Predicted distributions based on ecologically meaningful variables.<br>• Growing availability of high-resolution bioclimatic and environmental datasets.<br>• Ensemble models improve predictions by averaging out algorithm-specific limitations. | • Predictions only as good as the data provided. Thus, predictions can be sensitive to spatial and temporal sampling biases, although rarefaction, filtering, and supplemental sampling can reduce the effects of sampling bias.<br>• Presence-only models sensitive to pseudo absence selection parameters.<br>• Models usually only predict suitability rather than estimating abundance or population trends over time. | Low – Extensive literature and software resources. |

Yellowhammer © Mark Hamblin 2020Vision



# Limitations

Training volunteers to survey target species of bird and mammal enabled the project to map species distributions at 1 km resolution across a farmed landscape. We believe that with further development and validation, it may offer a viable cost-to-scale effective approach to assessing trends in biodiversity at landscape-scale. A number of limitations must be addressed to ensure robust and reliable trend estimates can be determined by the approach.

- The primary limitation of approach was the result of the implications of the COVID-19 pandemic in 2020. This prevented surveys being conducted as planned in the bird breeding season, insect flight season, and plant flowering season. Winter distributions of birds are patchier than in the breeding season when birds occupy breeding territories. Adjustment to the planned survey period enabled the project to achieve the aim of testing the survey approach, and while it constrained the scope and usefulness of the data collected, the primary objective of mapping species distribution as presence/absence was met.
- Given the nature of the farmer cluster (patchy participation within the focal landscape) and the variation in participation of farms in surveys (not all participated), it was not possible to achieve complete coverage and map comprehensive species distributions. None-the-less, the principle of a volunteer led survey to map species distributions at landscape-scale was tested and demonstrated.
- It had been intended to validate the occupancy-abundance relationship with abundance data (i.e. the link between species distribution and population size) by surveying a sub-sample of target 1 km squares using the Breeding Bird Survey methodology[31] concurrently with the distribution mapping approach. The seasonal restriction brought about by the pandemic meant that this was not possible. Abundance and distribution is far more spatially aligned in the breeding season than in winter, so to attempt this during winter when bird distribution is far less territorial would not have supported a meaningful analysis.

# Next steps and recommendation

## Field survey

- Testing the approach as originally intended in the typical survey season for the target species.
- Validation of the occupancy-abundance relationship with abundance data is critical to the application of this approach. Occupancy trends tend to underestimate abundance trends, and this needs to be fully understood. It is feasible that species range may increase (i.e. in response to climate change) while abundance in occupied squares decreases. This appears to be a common pattern in European butterflies, for example. More research is needed on the relationship between occupancy and abundance trends in wildlife generally, and further testing of the approach presented here may offer an opportunity to do so, while supporting the development of species distribution mapping as a sustainable alternative to abundance focused surveys to monitor population trends.
- The development of a field survey app. using a platfom such as Mergin[32], which allow a custom recording form to be set up with automated storage in a geospatial database, will of substantial benefit to the approach.

## Application of national datasets to the assessment of biodiversity trends

To be widely and practically applied among the conservation practitioner community, the statistical advances in the combined use of structured and opportunistic data need to be made readily available to ecologists, through the development of flexible and easy to use software. The establishment of a knowledge transfer process at the academic-practitioner actioner interface.

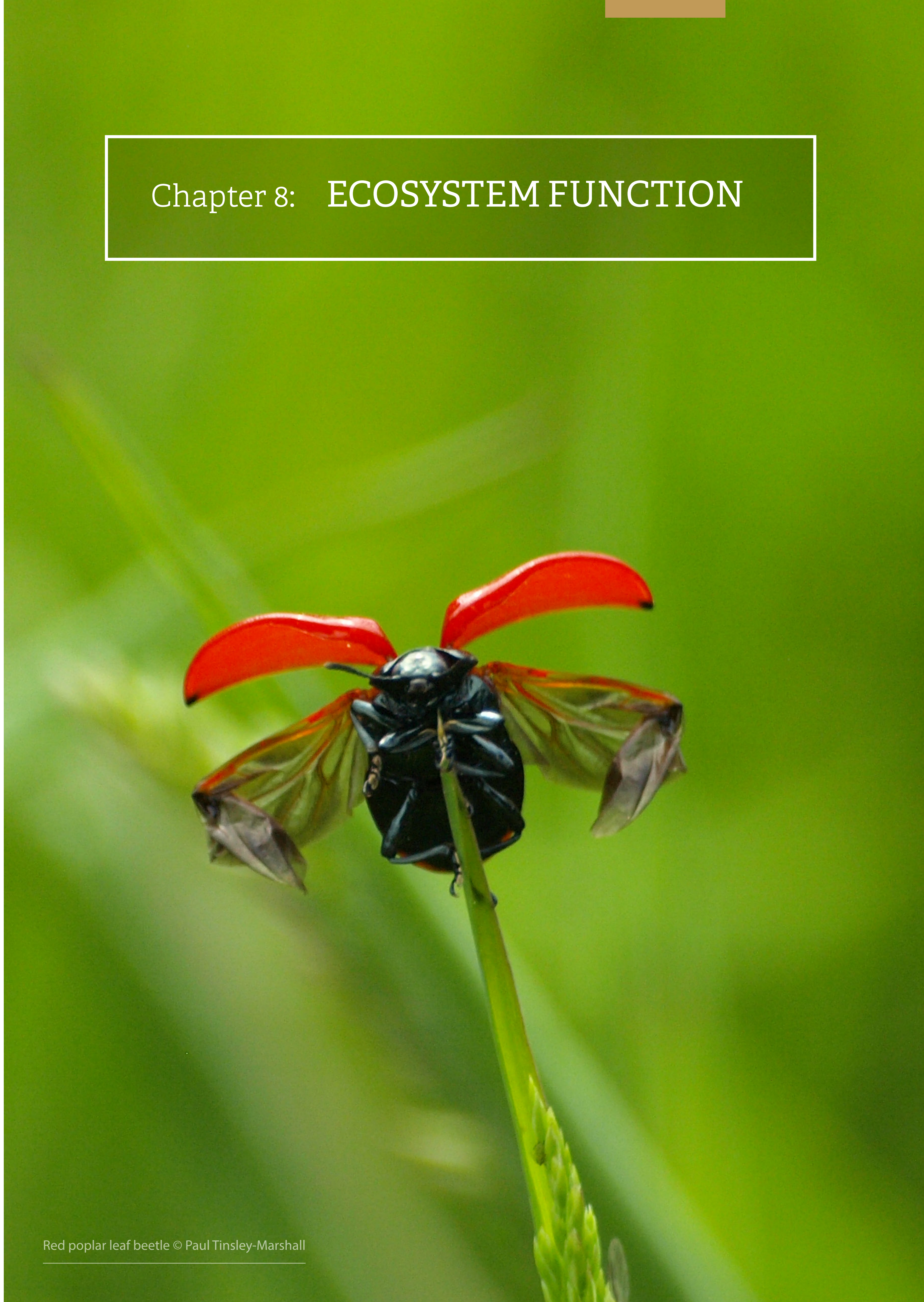
As a result of networks formed through the development of this project, Kent Wildlife Trust was invited to become a partner in a National Environment Research Council funded Knowledge Exchange Fellowship led by The UK Centre for Ecology and Hydrology. This project will bring the recent advances in statistical techniques for the use of existing structured and opportunistic survey data for species trend assessment at sub-national scales within reach of non-academic practitioners, through knowledge transfer and the development of accessible tools.

# Synthesis and application

Training volunteers to survey target species of bird and mammal enabled the project to map species distributions at 1 km resolution across a farmed landscape. If the approach can be validated and tested further, it has the potential to offer a monitoring solution to enable landscape-scale determination of trends in biodiversity. However, the potential application of existing national datasets to the assessment of county and sub county-scale trends appears to offer both a more sustainable and statistically powerful approach. This potential should be fully explored as a priority before further development of a field survey approach is undertaken, and it is recommend that practitioners seek to gain knowledge and understanding of the application of these techniques.

[31] https://www.bto.org/our-science/projects/bbs
[32] https://public.cloudmergin.com/






Red poplar leaf beetle © Paul Tinsley-Marshall

# Background and rationale

Ecosystem services can be defined as "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfil human life"[1]. Alternatively, "the set of ecosystem functions that are useful to humans"[2]. It would be almost impossible to list all ecosystem services, let alone the natural products that humans directly use or consume. The proper functioning of the world's ecosystems is critical to human survival, and both understanding the basics of ecosystem services and monitoring their state is essential. Entire volumes have been written on ecosystem services[3], culminating in a formal, in-depth, and global overview by hundreds of scientists: The Millennium Ecosystem Assessment[4,5,6].

The project developed an overview of ecosystem services and functions, detailed in **Table 8.1**. This provided a basis for the selection of a suitable metric with which to develop a practical approach to answering questions about landscape-scale outcomes for ecosystem functions and services.

Increasing biodiversity is usually associated with increasing ecosystem efficiency and productivity, stabilizes overall ecosystem functioning, and makes ecosystems more resistant to perturbations. Perception of biodiversity loss is particularly focused on extinction, especially those of large charismatic vertebrates. Nonetheless the actual proportion of species that are known to have gone extinct is relatively small. Just 80 species of mammal and 182 species of bird have been lost since 1500, representing 1.5% and 1.8%, respectively, of known species[7,8]. On the face of it, these figures would seem to be at odds with the notion that we are in the midst of the 'sixth mass extinction event' or that biodiversity is in crisis. However, evidence has recently begun to emerge suggesting that global wildlife is being affected far more profoundly than these relatively modest figures for actual extinctions might suggest. Anthropogenically mediated extinction is far outpacing background extinction rates, and we are transforming habitats at faster rates than ever before, drastically accelerating the loss of biodiversity.

Insects are a critical component of ecosystem function. Invertebrates are functionally far more important than large-bodied fauna, and in terms of biomass, bioabundance and species diversity, they make up the greatest proportion of life on earth. 41% of insect species are threatened with extinction globally, and there is increasing evidence for the decline of insects[9].

- In the UK 'wider countryside' **butterflies have declined by 46%**, and habitat specialists by 77%.
- Since 1850, **23 species of bee and flower-visiting wasp** species have **gone extinct.**

## The functional effect of insect decline is increasingly apparent:

- The **red-backed shrike**, a specialist predator of large insects, went **extinct in the UK** in the 1990s.
- UK populations of the **spotted flycatcher fell by 93%** between 1967 and 2016.
- Other once-common insectivorous birds have suffered similarly, including the grey partridge (**–92%**) nightingale (**–93%**) and cuckoo (**–77%**).

In developing an approach to monitoring ecosystem function at landscape-scale, it was recognised that addressing multiple components of ecosystem function was out of scope of the project. Consideration of the biodiversity crisis apparent in insect populations and the functional consequences of this decline on trophic integrity was the primary driving factor in the development of a landscape-scale monitoring approach to quantify aspects of ecosystem function and service.

[1] *Daily, G. C., ed. (1997). Nature's services: societal dependence on natural ecosystems. Island Press, Washington, DC.*
[2] *Kremen, C. (2005). Managing ecosystem services: what do we need to know about their ecology? Ecology Letters, 8, 468–479.*
[3] *Daily, G. C., Matson, P. A., and Vitousek, P. M. (1997). Ecosystem services supplied by soil. In G. C. Daily, ed. Nature Services: societal dependence on natural ecosystems, pp. 113–132. Island Press, Washington, DC.*
[4] *Millennium Ecosystem Assessment (2005a). Ecosystems and human well-being: synthesis. Island Press, Washington, DC.*
[5] *Millennium Ecosystem Assessment. (2005b). Nutrient cycling. World Resources Institute, Washington, DC.*
[6] *Millennium Ecosystem Assessment. (2005c). Fresh water. World Resources Institute, Washington, DC.*
[7] *MacPhee, R.D.E. & Flemming, C. (1999) "Requiem Aeternam: the last five hundred years of mammalian species extinctions". In MacPhee, R.D. E. & Sues, H.. Extinctions in Near Time: cause, contexts and consequences. Springer.*
[8] *Butchart, S. H. M., Stattersfield, A. J. and Brooks, T. M. (2006) Going or gone: defining 'Possibly Extinct' species to give a truer picture of recent extinctions. Bull. Brit. Orn. Club. 126A: 7–24.*
[9] *Goulson, D. (2019) Insect declines and why they matter. A report commissioned by the South West Wildlife Trusts. https://www.kentwildlifetrust.org.uk/sites/default/files/2020-01/Actions%20for%20Insects%20-%20Insect%20declines%20and%20why%20they%20matter.pdf*





# Development

| | |
|---|---|
| **1. Stakeholder contribution** | How stakeholders fed into the design of our approach:<br><br>• While not prioritised though the stakeholder consultation, the question 'How is ecosystem functionality changing?' was raised by stakeholders<br>• Ecosystem function was considered an organisational priority for Kent Wildlife Trust to address as part of the project. |
| **2. Audit and gap analysis** | *Through desktop research the project developed an overview of ecosystem services and functions to inform the selection of potential metrics for the assessment of landscape-scale outcomes of landscape-scale conservation (Table 8.1).*<br><br>*Reviewing this led to the selection of 'trophic integrity' as a desirable ecosystem function to monitor.*<br><br>*Insect populations were chosen as a metric, on the basis of the following:*<br><br>• *The biodiversity crisis apparent in insect populations.*<br>• *The highly significant and integral contribution of insects both intrinsically and extrinsically to a plethora of ecosystem functions and services across a suite of trophic levels.*<br>• *The provision of services and functions by insects across a broad range of functional units (populations, species, communities, functional groups).*<br>• *The provision of services and functions by insects at all spatial scales from local to global, providing a relevant and informative metric at landscape-scale.* |
| **3. Development and testing** | An existing survey method designed to monitor insect populations at county to national scales was identified. *The Big Bug Count* was conducted once across the UK in 2004 by the RSPB but had not been repeated. There was therefore an opportunity to utilise an existing baseline dataset and to enhance the usefulness of the 2004 survey by repeating it in Kent to compare insect numbers over time. This expedited progress towards the point of obtaining data that could be compared with a baseline, and enabled limitations in the original survey method to be addressed. |
| **4. Outputs** | • *OP8.1* **Case study - Bugs Matter:** *Citizen scientist-led monitoring of ecosystem function at landscape-scale demonstrates temporal difference in invertebrate abundance in Kent and South-East England.*<br>• *OP8.2* **Design specification for Bugs Matter mobile app.**<br>• *OP8.3* **Project Legacy - The Bugs Matter mobile app. and citizen science survey.** |


Green longhorn © Paul Tinsley-Marshall

ECOSYSTEM FUNCTION
Background and rationale | Development | Audit & gap analysis | Practical Approach | Limitations | Next Steps & recommendations | Synthesis & application

# Audit and gap analysis

*Table 8.1* **Overview of ecosystem services and functions, classified according to the Millennium Ecosystem Assessment, and their ecosystem service providers developed and augmented from the Millennium Ecosystem Assessment[10], Stroh & Hughes[11], and the Wetland Monitoring Framework and Manual[12].** 'Functional units' refer to the unit of study for assessing functional contributions of ecosystem service providers; spatial scale indicates the scale(s) of operation of the service. Assessment of the potential to apply this conceptual framework to the service is purposefully conservative and is based on the degree to which the contributions of individual species or communities can currently be quantified[13].

| Service | Ecosystem service providers/ trophic level | Functional units | Spatial scale | Potential to apply this conceptual framework for ecological study |
|---|---|---|---|---|
| Aesthetic, cultural, spiritual, educational, inspirational. | All biodiversity | Populations, species, communities, ecosystems | Local-global | Low |
| Ecosystem goods (food, fuel, materials, forage, biochemicals, genetic materials) | Diverse species | Populations, species, communities, ecosystems | Local-global | Medium |
| UV protection | Biogeochemical cycles, microorganisms, plants | Biogeochemical cycles, functional groups | Global | Low |
| Purification of air | Micro-organisms, plants | Biogeochemical cycles, populations, species, functional groups | Regional-global | Medium (plants) |
| Flood & erosion mitigation | Vegetation | Communities, habitats | Local-regional | Medium |
| Drought mitigation | Vegetation | Communities, habitats | Local-regional | Medium |
| Climate stability | Vegetation | Communities, habitats | Local-regional | Medium |
| Pollination | Insects, birds, mammals | Populations, species, functional groups | Local | High |
| Pest control | Invertebrate parasitoids and predators and vertebrate predators | Populations, species, functional groups | Local | High |
| Herbivory | Insects, birds, mammals | Populations, species, functional groups | Local | High |
| Predation | Diverse species | Populations, species, functional groups | Local | High |
| Carbon sequestration | Diverse species | Populations, species, communities, ecosystems | Local-global | High |
| Trophic integrity | Diverse species | Populations, species, communities, functional groups | Local-global | High |
| Purification of water | Vegetation, soil micro-organisms, aquatic micro-organisms, aquatic invertebrates | Populations, species, functional groups, communities, habitats | Local-regional | Medium to high* |
| Detoxification and decomposition of wastes | Leaf litter and soil invertebrates, soil micro-organisms, aquatic microorganisms | Populations, species, functional groups, communities, habitats | Local-regional | Medium |
| Soil generation and soil fertility | Leaf litter and soil invertebrates, soil micro-organisms, nitrogen-fixing plants, plant and animal production of waste products | Populations, species, functional groups | Local | Medium |
| Seed dispersal | Ants, birds, mammals | Populations, species, functional groups | Local | High |

[1] *Millennium Ecosystem Assessment (2005a). Ecosystems and human well-being: synthesis. Island Press, Washington,DC.*
[2] *Stroh, P. & Hughes, F., 2010, Practical Approaches to Wetland Monitoring: Guidelines for Landscapescale Long-term Projects, Anglia Ruskin University* http://www.nationaltrust.org.uk/document1355774442659/
[3] *Wetland Monitoring Framework and Manual* https://www.fensforthefuture.org.uk/admin/resources/downloads/wow-wp3.3monitoringframeworkandmanualfinal.pdf
[4] *Kremen, C. (2005). Managing ecosystem services: what do we need to know about their ecology? Ecology Letters, 8, 468–479.*

# Practical approach

## OP8.1 Case study: Bugs Matter – Citizen scientist-led monitoring of ecosystem function at landscape-scale demonstrates a temporal difference in invertebrate abundance in Kent and South East England.

### Introduction

A growing body of recent evidence[14] highlights population declines in insects and other invertebrates at global scales, the consequences of which are potentially catastrophic. Patterns and trends are nuanced however. Some insects are increasing, and while trends in some insect groups are well understood, there is a paucity of data for many others, and more research is needed. Invertebrates are a critical component of ecosystem function, and all functional groups (herbivores, detritivores, parasitoids, predators and pollinators) are at risk. Invertebrates are functionally far more important than large-bodied fauna, and in terms of biomass, bioabundance and species diversity, they make up the greatest proportion of life on earth. Invertebrates are food for numerous larger animals including birds, bats, reptiles, amphibians and fish. Almost all birds eat insects, and many of those that eat seeds and other food as adults must feed insects to their young. It takes 200,000 insects to raise a swallow chick. Insects provide a natural pest regulation function, and pollinate most of the world's crops. Without them we could not grow onions, cabbage, broccoli, chillies, most tomatoes, coffee, cocoa, most fruits, sunflower and rapeseed oil. Demand for synthetic fibres would surge because bees pollinate both cotton and flax. Insects also break down plant matter and recycle nutrients into the soil. Without any insects at all, most bird and amphibian species would go extinct, and we would be surrounded by the carcases of dead animals. Without the ecological functions provided by invertebrates, life on earth would collapse. As such, considerable conservation effort is targeted at invertebrates. The project tested an innovative invertebrate sampling technique conducted by citizen scientists to assess invertebrate abundance as a metric of the ecosystem services they provide, in South East England over a 15 year timeframe. It sought to address the paucity of invertebrate trend data in Kent, to address some of the limitations of the methodology, and to assess the potential of the method to provide a monitoring solution for landscape-scale outcomes more widely.

### Survey design

**1. Define landscape parameters:** the parameters of the study landscape were defined as the entire administrative extent of Kent and Medway. While the functional extent of this landscape in terms of the ecosystem service monitored is not delineated by its boundary, it was accepted that complete coverage of the UK was out of scope of the project. This limitation is addresses in *Next steps and recommendations* below.

**2. Define theme to be addressed:** the theme addressed by this approach was defined as invertebrate abundance, acting as a proxy for the ecosystem services provided by insect populations, and as a metric for insect population change.

**3. Articulate objective, question or hypothesis:** the objective of this approach was to quantify insect populations in Kent using a standardised approach and to make comparisons with pre-existing baseline data. **See OP3.6: Articulating the question and hypothesis testing.**

- H0: there is no evidence of variation in insect populations in Kent between 2004 and 2019.
- H1: there is evidence of variation in insect populations in Kent between 2004 and 2019.

[14] *Goulson, D. (2019) Insect declines and why they matter. A report commissioned by the South West Wildlife Trusts.* https://www.kentwildlifetrust.org.uk/sites/default/files/2020-01/Actions%20for%20Insects%20-%20Insect%20declines%20and%20why%20they%20matter.pdf





**4. Attributes of monitoring programmes**

Survey design was informed by the attributes from **OP3.3 Ordered list of attributes of monitoring programmes.** This output presents a ranking of attributes of monitoring programmes in order from most elemental to most aspirational. The table below details how the survey design considered and adopted these attributes.

| Attribute | | Comment |
|---|---|---|
| Most elemental | Objectives and questions defined | From the outset the hypothesis was articulated. |
| | Standardised methods and protocols | Standardised data collection used an established counting method, termed a 'splatometer'. |
| | Suitable, accurate, efficient sampling methods | The sampling method was established and tested in 2004 by the RSPB and is based on the concept of the *windscreen phenomenon*. |
| | Sufficient contributors | A large potential pool of volunteer citizen scientists provided sufficient contributors. |
| | Suitable and accessible identification resources | Not applicable. |
| | National, regional, or local coordination | County-level coordination was overseen by Kent Wildlife Trust. |
| | Efficient data entry, storage and processing systems | Data collection for this pilot study relied on inefficient paper-based recording, however this limitation was addressed as part of project legacy. |
| | Data is reliable and validated | Validation relied on accurate determination and counting by volunteers. A low requirement for technical knowledge afforded very little scope for error, and in the context of citizen science projects, the potential for error was deemed acceptable. |
| | Results and findings fed back to participants | Results were reported directly to participants. |
| | Sufficient contribution of specialist knowledge | No specialist knowledge was required by participants. |
| | Appropriate analytical and statistical approaches available | Generalised Linear Models provided an appropriate statistical approach to analysing the data. |
| | Good retention of contributors | The pilot survey reported here ran for one year. Retention of contributors is less critical for citizen science projects, as new contributors can be recruited, never-the-less, facilitating ease of and scale of participation is addressed as part of the project legacy. |
| | Mentoring, training and support for contributors | Non-technical approach required very minimal mentoring, training and support. |
| | Analytical and statistical approaches accessible | Generalised Linear Modelling is within the skill set of organisational staff. |
| | Change reported at appropriate intervals | Change was reported on the basis of baseline data availability (2004) and repeat survey (2019). |
| | Appropriate, scientific, sampling design | The 'splatometer' provide a standardised approach to sampling design. |
| | Simple reporting of widespread and common species/attributes available to all | Not applicable. |
| | Results disseminated widely | Results were reported directly to participants, more widely to organisational stakeholders, and reported in national and international media. |
| | Best practice shared between organisations and schemes | This document, the project conference, and ongoing networking shares the development of this approach and its application. |
| | Indicator/important species or attributes identified | Not applicable. |
| | Wide coverage by participants | The geographic extent of the study area was extensively covered by participants. |
| | Collection of supplementary data (i.e. habitat soil, weather) | Supplementary data on potential explanatory variables was collected (e.g. make, model and age of vehicle). |
| | Focus on important species, locations, habitats etc. | Not applicable. Focus is broad, landscape/county scale. |
| | Electronic data capture | Out of scope in pilot study, addressed in project legacy. |
| Most aspirational | Change reported annually | Addressed in scope of developments as part of project legacy. |

**5. Selecting indicator species(s):** Not applicable.

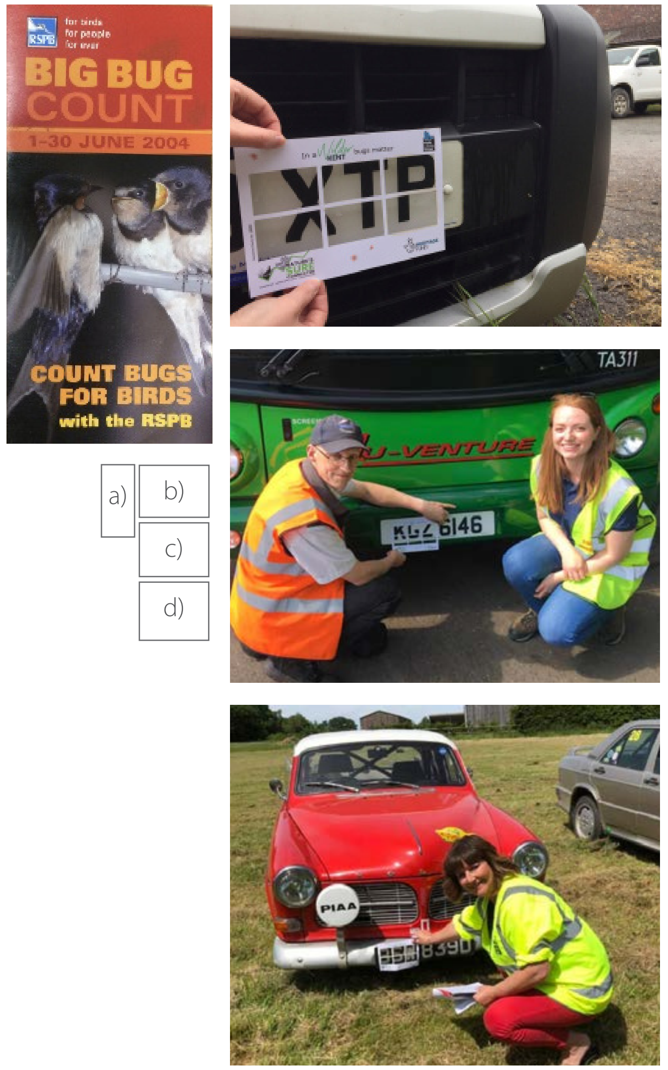
### 6. Practical approach

The *windscreen phenomenon*[15] is a term given to the anecdotal observation that people tend to find fewer insects squashed on the windscreens of cars now compared to a decade or several decades ago. This effect has been ascribed to major global declines in insect abundance.

*Insects are inadvertently sampled when they become squashed on vehicle windscreens and registration plates.*

**a) Survey method**

Using a standardised sampling grid termed a 'splatometer', members of the public were asked to record the number of insects and other invertebrates squashed on the number plate of their car, having first cleaned the number plate before commencing a journey.




*The 2004 RSPB-led 'Big Bug Count' (a), a 'splatomter' grid used to standardise counting of insects squashed on vehicle number plates, c) Kent bus company 'Nu-venture' took part in the survey, as did d) the Blackpalfrey Motor Club of Kent, enabling us to examine the effect of change in body styles of vehicles on insect numbers observed.*



[15] https://en.wikipedia.org/wiki/Windshield_phenomenon



**b) Results**

A national survey using this methodology led by the RSPB took place in 2004, and by repeating the survey in Kent in 2019 we were able to compare the abundance of invertebrates at landscape-scale between these points in time. Between 2004 (n=3838 journeys) and 2019 (n=667 journeys) there was a statistically significant reduction in 'splat density' of approximately 50%, from an average of 0.2 splats per mile to 0.1 splats per mile **(Figures 8.1 & 8.3a)**. This difference mirrors the patterns of decline widely reported by others[16,17]. It should be noted that this observation is based on data from only two points in time. Consequently it does not constitute a trend and cannot be interpreted as a decline. Insect populations are susceptible to many different influences that vary inter-annually. These include variation in weather, habitat management, disease and predation. The first and last year in a data series can also have a large impact on trends if abundance in these years is uncharacteristically high or low. To fully understand an insect population it needs to be monitored thoroughly at regular intervals over an extended timeframe to reveal genuine trends which then become clear despite inter-annual variation. More data over a number of years will be required to confirm the direction of any trend, however the observed pattern correlates with examples of decline reported elsewhere.

**Spacial analysis**

Route mapping used GIS software. Each journey was first assigned a unique ID number. The start, via, and end postcodes for each journey were converted into spatially referenced GIS points. Esri's ArcGIS Online Connect Origins to Destinations tool was used to map the routes between them along the road network. All the route lines were merged and points calculated at 100m intervals along the simplified line layer. These points were buffered into polygons large enough to overlap all the route lines along different carriageways of a single road. A spatial join was used to calculate the count of journeys and mean splat density from the all the original route lines corresponding with each buffered point and put these into the attributes for each buffer polygon. These buffer polygons were then saved as centroid points, retaining the attributes. To visualise sample size spatially, the points were buffered once more, in proportion to the count of journeys each one represents. To visualise splat density, the symbology for the points was assigned using a graduated colour ramp.

**Statistical analyses**

Statistical analyses were performed using the software R 2.10.1 for Windows following established techniques,. A Generalised Linear Model (GLM) was used to test the null hypotheses a) that there was no difference between years in the rate of bug splatter and b) that there was no effect of vehicle age on the rate of bug splatter. Explanatory variables were included in each initial model. Examination of histograms of the data revealed a strong negative skew in each response, as is typical of count-derived data, and examination of dispersion in the response variables revealed over-dispersion. To comply with model assumptions, analyses were therefore performed using GLM's with a quasi-Poisson error structure, appropriate for over-dispersed count derived data. As only one explanatory variable was modelled, these models were the Minimum Adequate Model (MAMs). All MAM's were checked for goodness of fit by plotting the residuals against the fitted values to look for evidence of heteroscedasticity, and the ordered residuals against the normal scores to look for evidence of non-normality of errors. To plot graphical representations of each model, the function allEffects from library(effects) was used to extract the model estimates and parameters, and the estimated mean and standard error (splat density) and 95% confidence intervals (vehicle age) plotted against the explanatory variables.

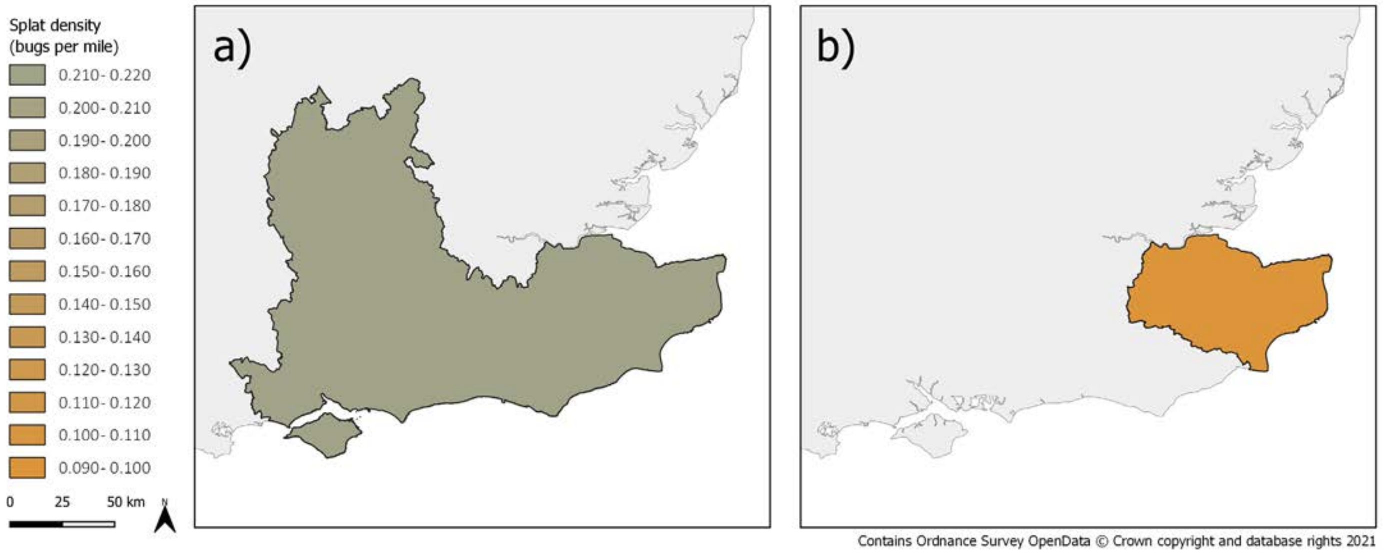



*Figure 8.1* **The difference in 'splat density' recorded on vehicle journeys between a) 2004 (in South East England) and b) 2019 (in Kent).** Between 2004 and 2019 there was a statistically significant difference in 'splat density' of the order of approximately 50%, from an average of 0.2 splats per mile to 0.1 splats per mile, in 2004 (n=3838 journeys) and in 2019 (n=667 journeys).

[16] *Hallmann, CA, Sorg, M, Jongejans, E, Siepel, H, Hofland, N, Schwan, H, Stenmans, W, Müller, A, Sumser, H, Hörren, T, Goulson, D and de Kroon, H. (2017). More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PlosONE 12.*

[17] *Fox, R., Parsons, M.S., Chapman, J.W., Woiwood, I.P. Warren, M.S. & Brooks, D.R. (2013). The state of Britain's larger moths 2013. Butterfly Conservation & Rothamsted Research Wareham, Dorset*

The project addressed two limitations of the 2004 survey. Firstly, in the 2004 RSPB survey participants were not provided with guidance on journey length, and a large number of long journeys spanning several counties resulted in the data providing poor spatial resolution of variation. Only variation between regions was resolved in the 2004 data, but by encouraging participants to submit data from both short and long journeys, it was possible to map spatial variation in 'splat density' within Kent **(Figure 8.2)**.

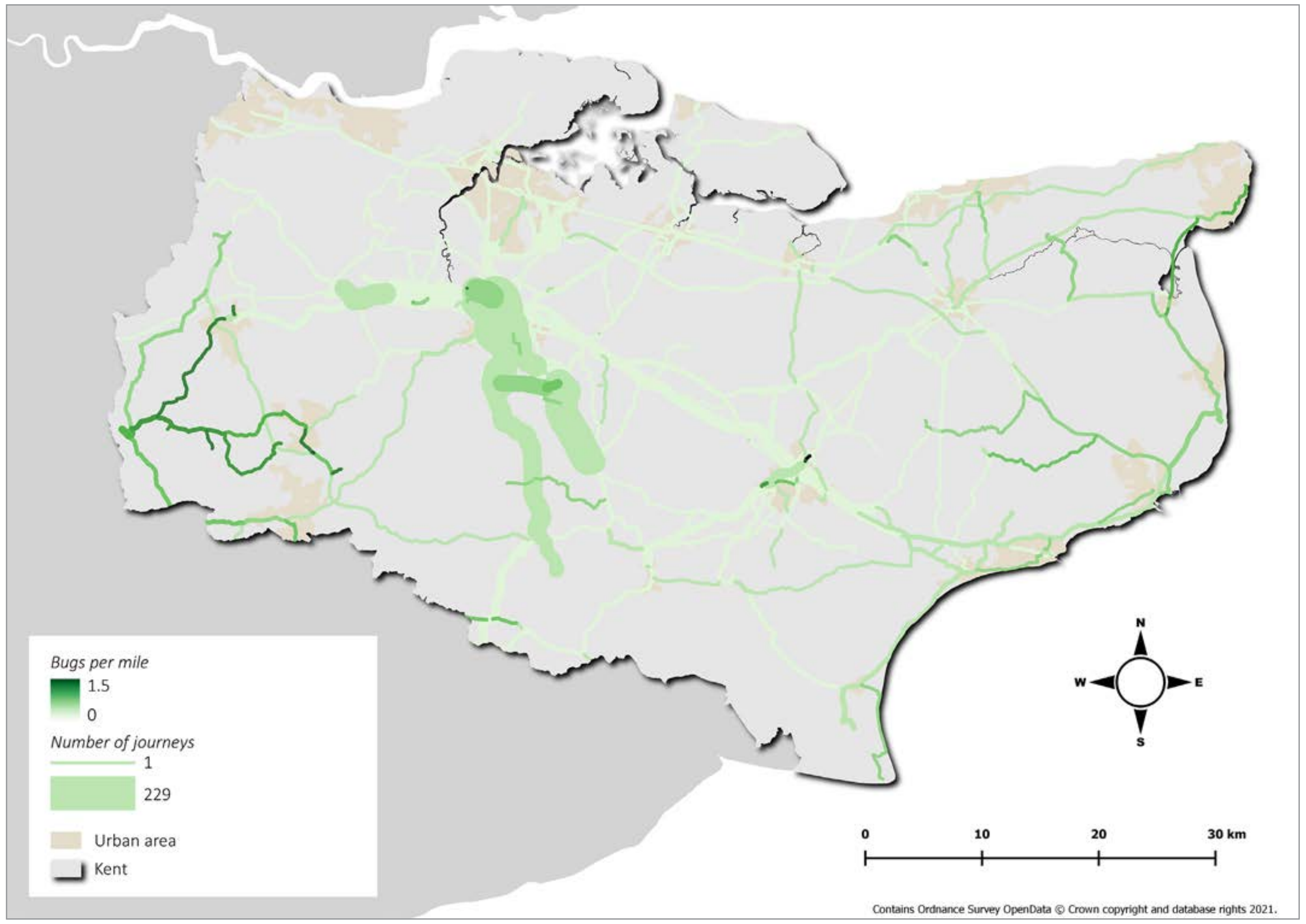



*Figure 8.2* **Spatially referenced heat map of the variation in splat density recorded from vehicle journeys in Kent in 2019.** Wider tracks indicate more samples (journeys), and darker tracks indicate higher average density of invertebrates, so that the pattern of variation in abundance is independent of sampling effort.






The second limitation the project addressed concerned a criticism levelled at the methodology in terms of the effect of vehicle design on the rate of invertebrate sampling. Modern cars are more aerodynamically designed than in the past, and changes over time may affect the numbers of insects getting squashed. We actively recruited classic car owners to take part in the survey, allowing us to collect data using cars manufactured between 1957 and 2018. We found a small but statistically significant positive relationship between vehicle age and splat density, suggesting that modern cars sample more invertebrates than older cars **(Figure 8.3b)**. This suggests that the signal from the difference in insect abundance is strong enough to be apparent inspite of more efficient sampling by newer vehicles.

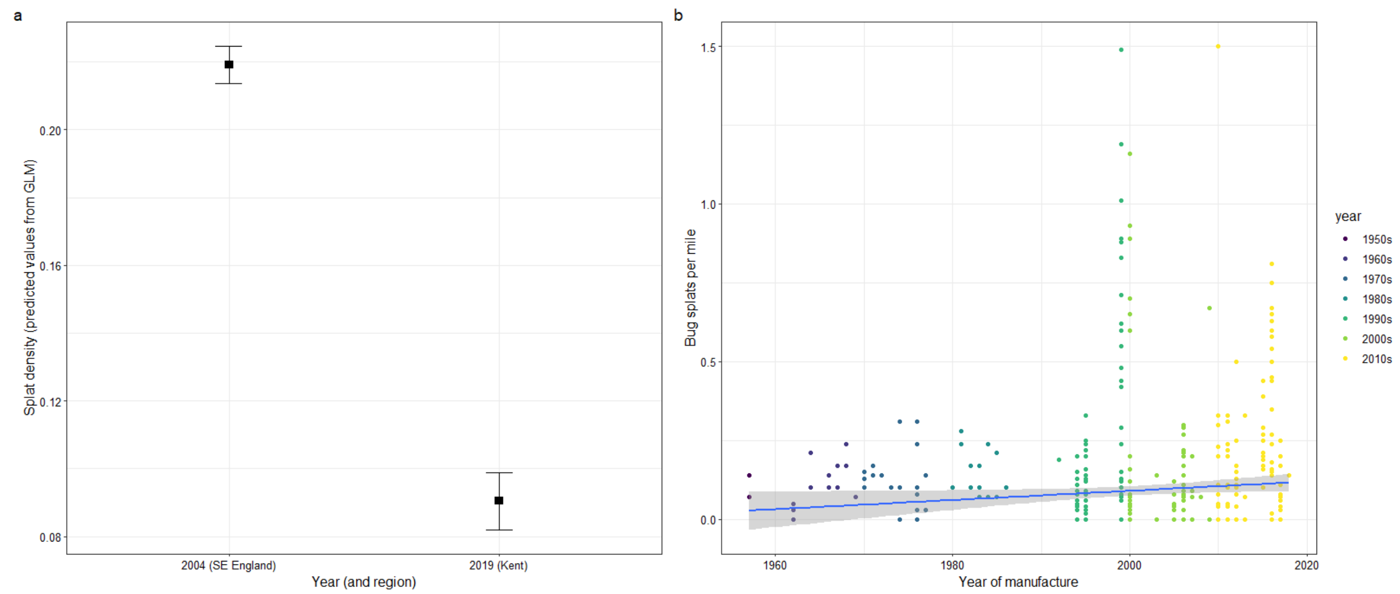



*Figure 8.3* **a) Model estimates and confidence limits of the difference in splat density recorded on vehicle journeys in 2004 (in SE England) and 2019 (in Kent). b) The relationship with confidence intervals, between splat density and age of vehicle predicted by a Generalised Linear Model.**

*Table 8.2* **Effect sizes, standard errors and exponents of a Generalised Linear Model of the temporal difference in splat density observed in overlapping regions of South East England between 2004 and 2019.**

| Year and region | Estimate | Exponent (mean) | Std. Error | t value | P |
|---|---|---|---|---|---|
| **2004 South East** | -1.51786 | 0.2191804 | 0.02501 | -60.683 | <0.001*** |
| **2019 Kent** | -0.88471 | 0.09048511 | 0.09688 | -9.132 | <0.001*** |

***Notes:*** *Estimate: estimate of the model intercept indicating the change in response per unit increase in the explanatory variable. Std. Error: standard error of the model estimate. t-value model t-statistic. P: model p-value. Asterisks indicate the level of significance: P < 0.05 = *, P < 0.01 = **, P < 0.001 = ***. P values for significant effects are taken from the model output of the minimum adequate model.*

*Table 8.3* **Effect sizes and standard errors of a Generalised Linear Model of the effect of vehicle age on splat density of insects squashed on number plates.**

| Year and region | Estimate | Std. Error | t value | P |
|---|---|---|---|---|
| **Intercept** | -37.654614 | 16.402368 | -2.296 | 0.0220* |
| **Decade of manufacture** | 0.017615 | 0.008192 | 2.150 | 0.0319* |

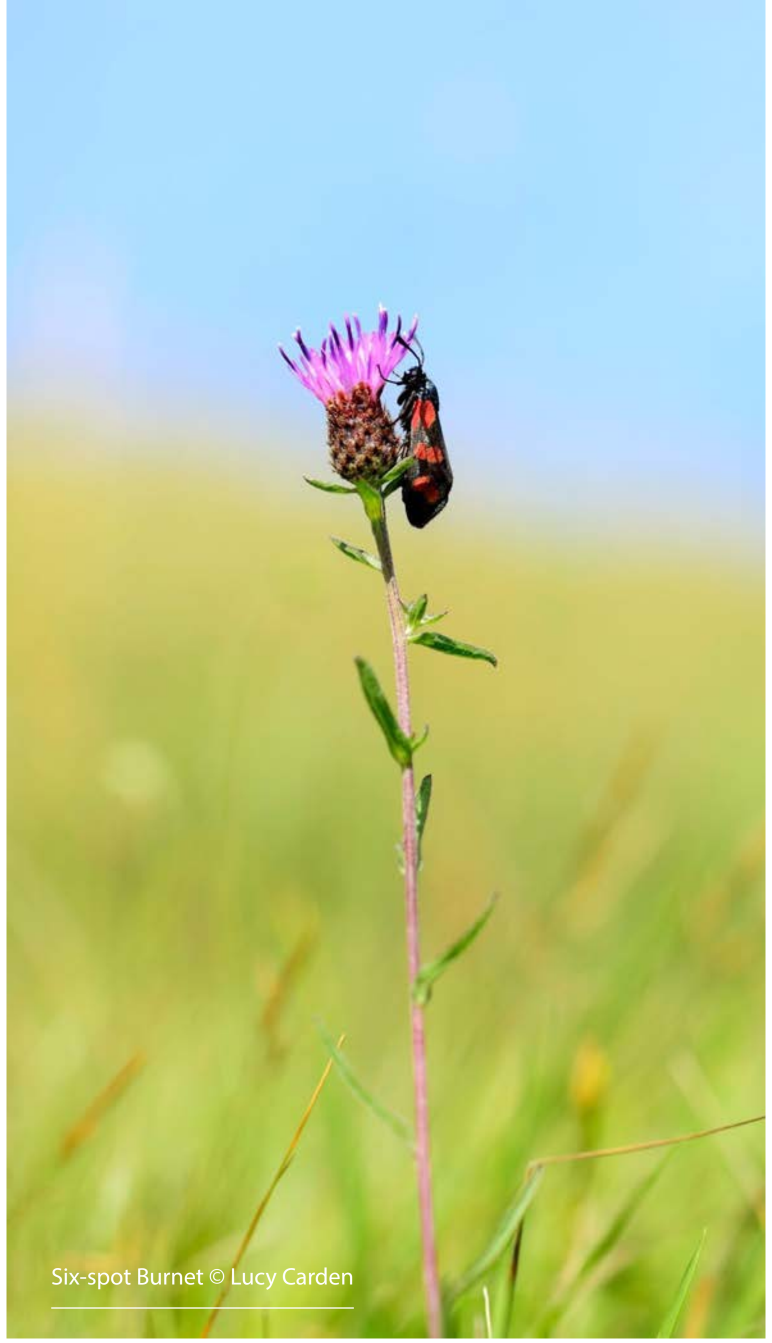
***Notes:*** *Estimate: estimate of the model intercept indicating the change in response per unit increase in the explanatory variable. Std. Error: standard error of the model estimate. t-value model t-statistic. P: model p-value. Asterisks indicate the level of significance: P < 0.05 = *, P < 0.01 = **, P < 0.001 = ***. P values for significant effects are taken from the model output of the minimum adequate model.*





# Limitations

- The survey provided a meaningful comparison of the variation in insect numbers, however various limitations must be addressed to ensure robust and reliable trend estimates can be determined by future iterations of the survey.
- Increasing the frequency interval of data collection, ideally to annually, would enable greater confidence to be established in any trend observed over time, and to confirm whether any variation represents a decline rather than simply reflecting an inter-annual effect caused by naturally occurring variation in drivers of insect population numbers such as weather, predation and disease.



Six-spot Burnet © Lucy Carden

- Increasing sample size both through citizen scientist participation and number of journeys undertaken would provide greater confidence in the reliability of both insect numbers and trend assessment. A statistical power analysis to determine the sample size required to reliably determine change in insect numbers is recommended. More data requires greater participation by the public. Experience suggests that citizen science surveys must be as easy as possible and present as few barriers to participation as possible to maximise numbers taking part. The project ran this pilot survey in 2019 using paper forms and spread sheets, which are not conducive to mass participation on the scale required.
- Spatial coverage was restricted to the road network. While spatial variation in insect numbers was apparent, this is inherently spatially confounded with the road network itself, and with the frequency of journeys made within it. The volume of data is skewed heavily to larger, busier roads. It is unlikely that the method can be used to reliably determine comprehensive intra-county variation in insect numbers.
- Spatial coverage was also restricted to a single county. While the approach may provide a useful assessment at county-scale, it did not capture inter-county and national scale variation in insect numbers. To maximise the potential of the approach to provide useful data over the scales at which the ecosystem services provided by insects operate, coverage should be expanded to other counties, and ideally nationally. There is a potential for the approach to have global application and relevance.
- The spatial resolution and coverage of data from 2004 was not identical to 2019, making only a coarse comparison of South East England and Kent possible. Some of the variation in insect numbers may be explained by spatially confounded variables not accounted for in the analysis. Repeat survey at county scales, or more optimally at a national scale, would provide more a reliable estimation of variation and trends.
- Vehicle age provided only a coarse metric of the potential for aerodynamics to influence the rate of insect sampling by vehicles. Capturing more detail on the design and physical characteristics of vehicles used in the survey, as well as age, would enable more reliable determination of any effect.

# Next steps and recommendations

To address the limitations of the approach and the barriers to participation by potential volunteer citizen scientists the project produced a specification for a mobile app. that aims encourage and facilitate wider participation. Limitations in the method addressed by the first iteration of the app. include enhanced spatial mapping functionality, and the ability to factor vehicle design (aerodynamic influence) and journey speeds into analyses in addition to vehicle age. Subsequent iterations of the app. might provide the opportunity to account for real-time traffic volume and to assess the speed threshold above and below which invertebrates are sampled. Further analysis will enable the impact of higher traffic volumes than in the past to be addressed.

## OP8.2 Design specification for Bugs Matter mobile app.

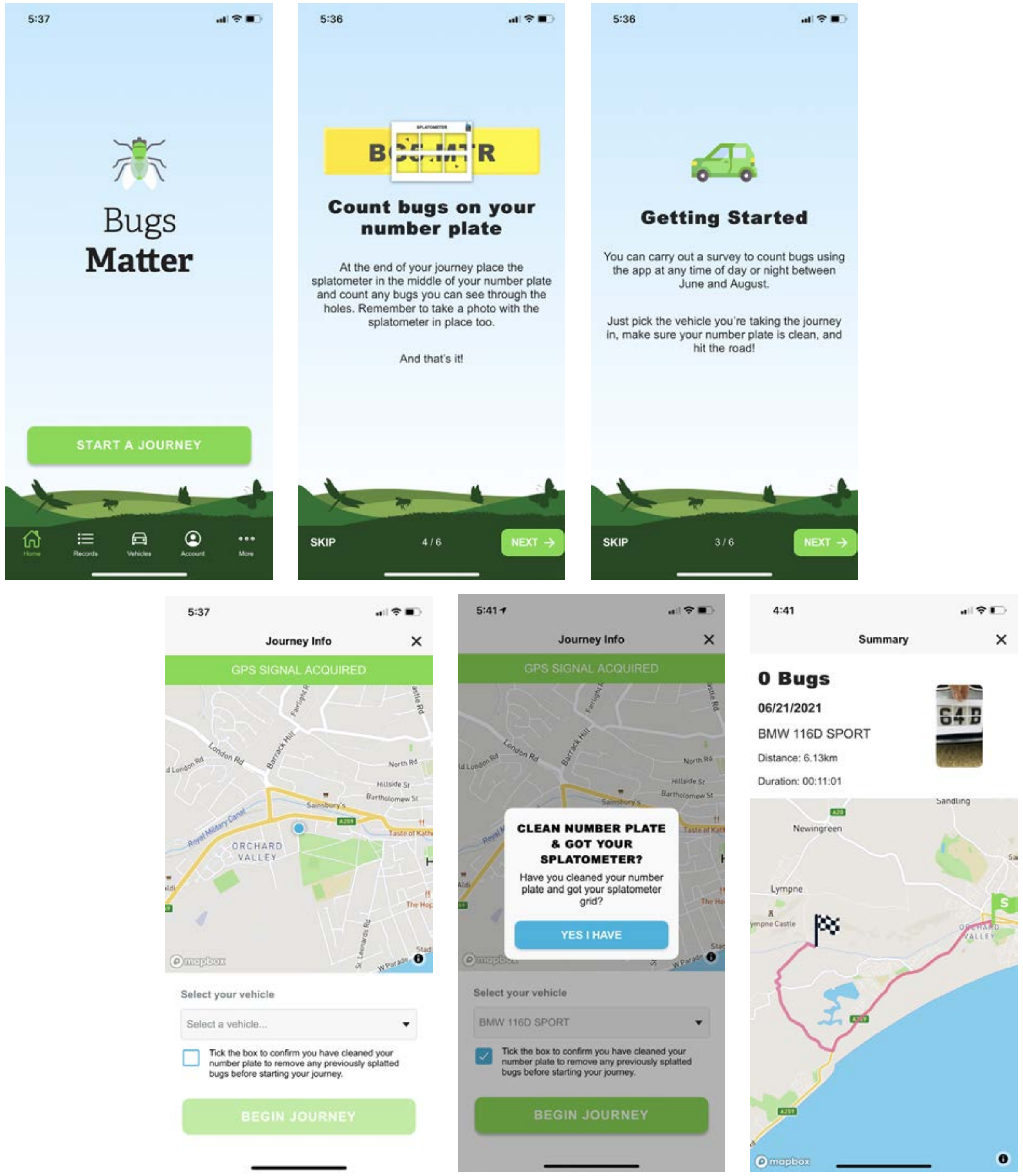
| Feature | Essential | Desirable | Aspirational |
|---|---|---|---|
| Available on most popular platforms (Android and IOS). | ✓ | | |
| Unique user ID. | ✓ | | |
| Vehicle age, make and model and other body style data captured through user provided vehicle registration. | ✓ | | |
| Unique journey ID. | ✓ | | |
| Manual turn-on of route recording and spatial location of journey start and end points recorded. | ✓ | | |
| Average journey speed. | | ✓ | |
| Recognise that the vehicle has stopped during journey and prompt the user to stop route tracking and count sample, or provide option to dismiss and continue journey and route tracking. | | | ✓ |
| Route mapped to road network and saved as a GIS .shp file. | ✓ | | |
| Date recorded (dd/mm/yyyy). | | | |
| Journey start and end recorded (24hr clock). | ✓ | | |
| Rain during journey (user manual entry yes/no at end of journey). | ✓ | | |
| Road classes of route captured: single lane, 2 lane A or B, dual carriageway/ motorway. | ✓ | | |
| User manual entry of count of insects within splatometer on number plate at the end of journey, by user (see notes below) or: | ✓ | | |
| Artificial Intelligence counts of insect sample from a photo of number plate. | | | ✓ |
| Data submitted via database hosted online, exportable as .csv. | ✓ | | |
| Testing of prototype app & amendments/improvements made. | ✓ | | |
| Reminder to user that number plate must be cleaned before each journey. | ✓ | | |
| Seasonality – reminder to user of survey period June-August. | | ✓ | |
| No data stored on the mobile phone where it could be manipulated by user to avoid validity of the data being questioned. | ✓ | | |





## OP8.3 Project Legacy - The Bugs Matter mobile app.

As part of the legacy of the project, funding for the development of the app. was secured, and a developer appointed. At the time of writing the app. is available and free to download publicly in app. stores, and the Bugs Matter mobile app. survey will launch in June 2021. There is a significant opportunity for others to promote the app. and to collaborate with Kent Wildlife Trust to monitor and understand trends in invertebrate abundance throughout the UK. Three other Wildlife Trusts, Essex, Gwent and Somerset, and Buglife, will promote the survey in 2021 alongside Kent Wildlife Trust, with additional support from the RSPB.




*Screenshots of the Bugs Matter mobile app.*

## Target audience

The target audience for the app. is broad, including adults, children and families, Wildlife Trust members (both adult and Wildlife Watch), partners and contractors of Wildlife Trusts, and the general public. While it relies on a vehicle being driven, the survey can be conducted by both drivers and passengers. In addition to engaging members and volunteers, Kent Wildlife Trust successfully recruited bus drivers, contractors and participants in a classic car rally. We believe there is a large potential audience who can be engaged with the app. Children can conduct the survey on the school run, day trips and holidays with parental supervision and appropriate health and safety guidance.

## Opportunity

The app. is free to download publicly, and development costs have already been secured. There is an opportunity for any and all Wildlife Trusts, environmental non-governmental organisations and other organisations to collaborate with this project, and baseline data exists for the  whole of the UK from 2004. Kent Wildlife Trust has the expertise and capacity to handle data processing, analysis and reporting, though data from other counties will be shared, and collaborative working encouraged. There are opportunities for the app. to drive the engagement of new audiences.

## Legacy

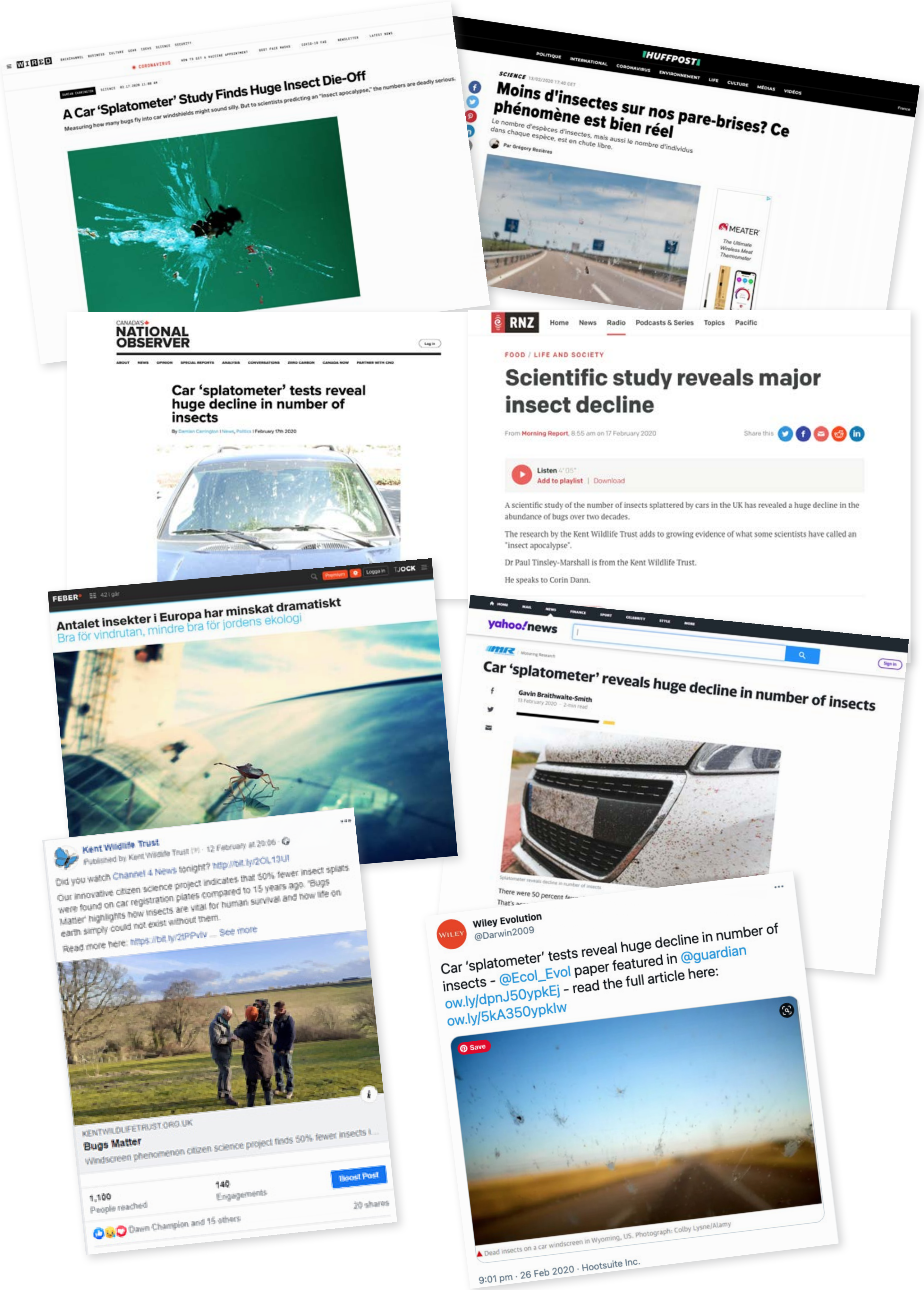
The Bugs Matter app. has the potential to provide a lasting and impactful legacy. It will provide a product that facilitates the collection of vital data that will fill a large gap in the evidence whilst also engaging significant new audiences in a citizen science project with a regional and national focus. It will allow us to establish, with confidence, what is happening to insects at county, regional and potentially national scale. This will in turn provide a tool to drive positive action and monitor change, and to continue to raise awareness around this critical issue.

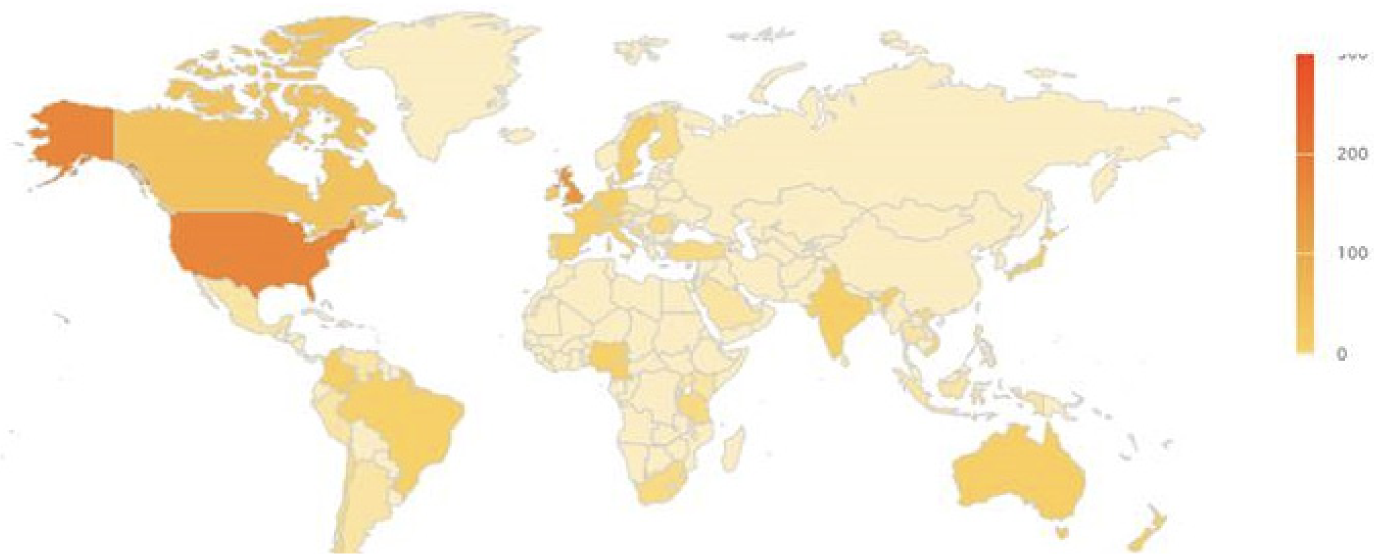
## Profile and engagement

Kent Wildlife Trust's pilot survey attracted national and international attention. To date its has gained 55 pieces of coverage with an estimated potential reach of 271 million world-wide. Our report was picked up by the Channel 4 news team and led to a prime time news piece with Jon Snow, an article both online and offline in The Guardian and interviews on the BBC World Service, Austrian National Radio (The Splatometer: How it works) and The Splatometer: What's at stake, Radio New Zealand – Morning Report. It was also featured in IFL Science, The Canary and WIRED.

We believe the level of media attention this project has already achieved is indicative of the profile this project can achieve. An app. of this kind has the potential to facilitate engagement on the scale of projects such as the Big Garden Birdwatch and Big Butterfly Count.


Media coverage of the Bugs Matter survey.






*Heat map of global media coverage of Bugs Matter survey.*

## Next steps and recommendation

Having tested and developed this approach, we believe it provides a practical solution for others to adopt and roll out in other landscapes and counties. We recommend others adopt and test this approach as a means of quantifying a critically important aspect of ecosystem function and have developed a solution to enable this. At the time of writing the following steps have been taken:

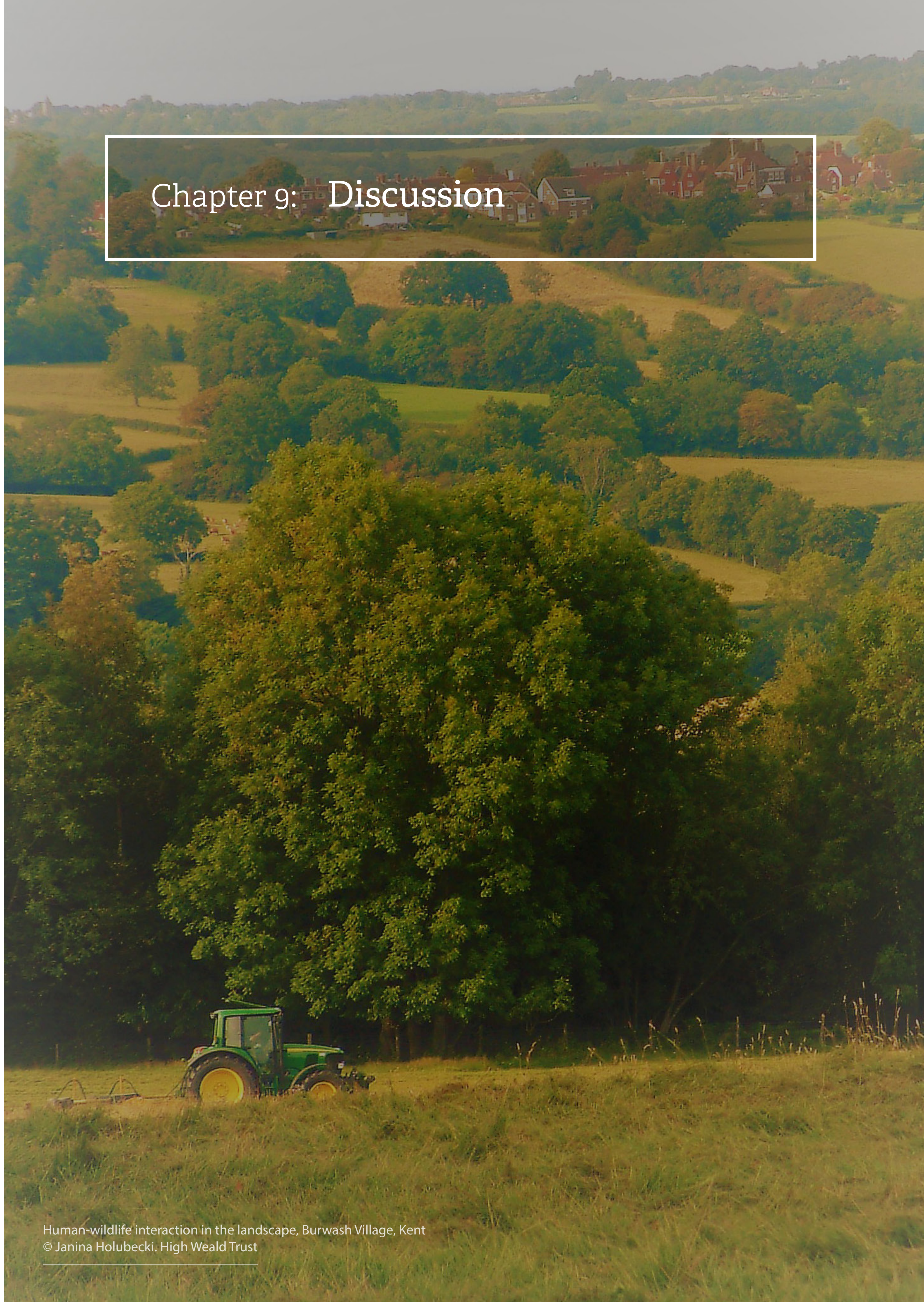
- Partnership working: the success of the pilot study, and the opportunities offered by the Bugs Matter app. have been disseminated to the wider Wildlife Trust movement, and external partners.
- The potential to roll the survey out nationwide would address limitations around defining a functionally delineated landscape and maximise the potential and usefulness of the data. This is being explored with partner organisations.
- A marketing campaign and package has been developed.
- The launch of the Bugs Matter app. survey is scheduled for June 2021, and it will launch nationally in partnership with Gwent, Essex and Somerset Wildlife Trusts, BugLife, and with support from the RSPB.
- The resources and expertise to support data analysis and reporting have been identified and secured within Kent Wildlife Trust.

## Synthesis and application

This approach successfully allowed the project to quantify a difference in the abundance of invertebrates over time from a baseline established in 2004. This baseline data exists for the whole of the UK. The approach has the potential to add to the growing body of evidence for significant invertebrate declines in the UK and provides a metric of the functional provision by invertebrates within ecosystems. We believe it would be feasible to role this approach out at county, regional, national and even international scales, and that the pilot study conducted by the project provides a model and resources for others to adopt.

An increasing number of studies are accumulating evidence of insect declines, and associated consequence for ecosystem functions. It is important to recognise that these patterns and trends are often nuanced, and that local conditions and choice of analytical approach may mean that results reported locally or regionally may not reflect patterns everywhere. The media uptake of negative trends from short time series data such as those presented here for example, may be acting to exaggerate the perception of an 'insect Armageddon', with potential consequences for public confidence in research. We recognise and stress that the results we have reported here do not constitute a trend, and advocate strongly for data collection over extended timeframes to help fill the gaps in the evidence for trends in insect populations. We believe that the widespread adoption of the Bugs Matter survey, now facilitated by the app., will provide a replicable and scalable approach for the generation of evidence to drive positive action for insects and other invertebrates at landscape-scale.





# Chapter 9: Discussion

Human-wildlife interaction in the landscape, Burwash Village, Kent
© Janina Holubecki. High Weald Trust

# General synthesis and application

The outcomes and outputs of this project are numerous and varied, ranging from the design of novel methods, approaches and concepts, to demonstrating new ways of collaborative working amongst conservation practitioners. Collectively, these outcomes support the project aim of developing new approaches that can be broadly applied to evidencing landscape-scale conservation outcomes.

Conservation organisations share common objectives for improving the resilience of ecological networks though landscape-scale conservation that can only be realised through the combined contribution of multiple actions, on multiple sites, by multiple stakeholders. Recognising this, the project employed a collaborative approach to developing the framework presented in this report. Landscape-scale conservation requires monitoring a complex matrix of conservation interventions and policies in space and time, which presents numerous challenges for conservation practitioners. Through a collaborative approach we reached agreement on the most important themes to address, which enabled the project to focus on the approaches which were most likely to be of greatest benefit to the conservation community.

The project developed a practical framework structured around a series of logical steps to inform the creation of monitoring objectives and programmes. By adopting, testing and developing the approaches presented, the conservation community can benefit and work to further advance best practice in evidencing the outcomes of landscape-scale conservation. By doing so, more and better evidence of the outcomes of landscape-scale conservation can be gathered, which will better inform and improve decision-making going forward.





# General Limitations

The framework presented involved key stakeholders, makes advances towards best practice, is evidence-led, a collection of guidance and case studies, and a foundation upon which to improve our shared capacity for evidencing conservation action at landscape-scale. It is not intended to be fully comprehensive, it is not designed to meet every conceivable need, and is not the only solution to the challenges of evidencing landscape-scale conservation outcomes. The project team welcome constructive feedback. Readers are encouraged to test, adopt and develop the approaches offered, to form networks to share experience and learning, and to further develop best practice in monitoring outcomes of landscape-scale conservation. Collective and coordinated action is needed if we are to establish common approaches, and the widespread testing of the approaches presented here, coupled with further development, is needed. By adopting common approaches, the collective power of evidence gathered using consistent, standardised methods can leverage in policy and practice can be fully realised by the conservation community.

Testing the effectiveness of specific conservation interventions was a suggestion put forward by stakeholders, though was beyond the scope and remit of this project. Evidence-based practice is essential for effective conservation[1]. One challenge when applying evidence-based conservation practice is that the underlying literature is sparse and uneven. An analysis of the literature on tests of conservation interventions found that of 2,399 potential conservation interventions collated by *www.conservationevidence.com*, 35.3% had not been tested, and 20.2% had only one test. In addition, 13.5% of the interventions assessed were ineffective or even harmful[2]. These include routinely implemented interventions. There is an urgent need to fill knowledge gaps and increase the reliability of evidence by testing interventions in different contexts, including at landscape-scale, and conservation practitioners can make a valuable contribution to this. This theme is discussed in more detail under Conservation Evidence in the next steps and project legacy section below. Landscape-scale conservation is a broad and complex subject, and it was recognised at the outset that developing a fully comprehensive monitoring framework was outside of the scope of the project. A focus on the key themes prioritised by stakeholders precluded the development of approaches in other areas, including the wealth of marine policy and management actions (though the blueprint for a land management mapping tool presented in Chapter Four makes provision for mapping marine management), habitat mapping, a comprehensive suite of landscape-scale habitat quality metrics, comprehensive assessment of ecosystem services, invasive species, monitoring threats and the effectiveness of their mitigation, spatial planning and prioritisation of conservation action, data sharing, and many more. Some of these themes are picked up by other organisations. For example, The UK Centre for Ecology and Hydrology (CEH) now provides accessible landcover data for the UK, and others require further development and coordination.

The project has developed mechanisms by which large-scale outcomes can be assessed, however a key challenge in evidencing outcomes at landscape-scale is finance. Funds need to be ring-fenced for the monitoring of nature's recovery, recognition of this is needed by government, and coordination at a national-scale is required. There remains a widespread challenge in implementation of landscape-scale monitoring, and the opportunity to embed effective practice in the delivery of Local Nature Recovery Strategies, and the wider Nature Recovery Network must be capitalised upon.

[1] *Sutherland, W.J. & Wordley, C.F. (2018) A fresh approach to evidence synthesis. Nature 558: 364–6. doi: 10.1038/d41586-018-05472-8*
[2] *Christie, A.P., Amano, T., Martin, P.A., Petrovan, S.O., Shackelford, G.E., Simmons, B.I., Smith, R.K., Williams, D.R., Wordley, C.F.R. and Sutherland, W.J. (2021), The challenge of biased evidence in conservation. Conservation Biology, 35: 249-262. https://doi.org/10.1111/cobi.13577*

# Next steps and project legacy

## More

The project developed a blueprint for a tool to capture data on the area of land managed positively for conservation that can be recreated by others in open source and proprietary GIS platforms, to gather similar landscape-scale data on a county or regional basis. To maximise the potential benefit of this approach, a single platform shared and used consistently by conservation organisations nationwide is needed. Whilst the tool designed in this project has the potential to be used at a national scale, its widespread dissemination for national contributions was outside of the scope and remit of the project. Therefore, a logical next step would be to establish a collaborative working group of stakeholders to work towards a common, national approach. Such an undertaking would need significant investment and coordination; however, it would provide wide-reaching benefits for the conservation community in terms of the application and influence of conservation evidence on land use and nature conservation policy both locally and nationally. Kent Wildlife Trust will continue to implement and encourage stakeholders to submit data to the tool to feed into the monitoring and reporting of landscape-scale conservation in Kent.

## Better

As remote sensing approaches for assessing habitat quality are developed, we anticipate a need to establish common metrics and assessment criteria against which habitat quality can be assessed, and to align and validate these with common standards. Assessing key habitat attributes, such as structure, management and quality at landscape-scales must be cost-effective, and while this project demonstrates that remote sensing offers some cost-to-scale effective solutions, a comprehensive analysis of habitat quality attributes remains out of reach. At present the detection of individual species is at best challenging and expensive, and at worst impossible. Hyper-spectral sensors mounted on aircraft can be used for individual species detection (for example the Woodland Trust have surveyed woodlands for Rhododendron using this approach) but widespread application to species level identification is prohibitively expensive and technically challenging. As remote sensing increasingly becomes used as a means of mapping and monitoring habitats, the application of consistent standards and common metrics, validated by ground truthing of models will be necessary. Some work to develop these ideas is detailed within the report, though significant investment and coordination will be needed for consistent, effective application of remote sensing techniques. The Common Standards Monitoring approaches for SSSI habitat condition assessment may offer a model for the development of a similar set of standards for the application of remote sensing to the assessment of habitat quality. There is a key role for scientists and specialist remote sensing practitioners to play in the development of common standards.

## Joined

Connectivity modelling approaches coupled with field surveys to validate predictions, offer an effective means to assess landscape-scale connectivity, beyond simply modelling the potential or theoretical likelihood of landscapes providing enhanced connectivity as a result of conservation action. Importantly, validating such models with field survey data improves their subsequent use and application by strengthening evidence for and improving the effectiveness of landscape-scale conservation action. By adopting the criteria for selecting suitable landscape indicator species developed by the project, and further enhancing the ecological meaningfulness of occupancy data by including evidence of species completing stages of their lifecycle in newly occupied patches, gathering robust evidence of functional connectivity can become routine in the assessment of landscape-scale conservation outcomes. Further collaborative work towards common standards that can be used to infer when functional connectivity has been achieved will improve the usefulness and applicability of the approach.

## Biodiversity

Training volunteers to survey target species of bird and mammal enabled the project to test an approach to map species distributions at a 1 km resolution across a farmed landscape. If the approach can be validated and tested further, it has the potential to offer a monitoring solution to enable cost effective landscape-scale determination of trends in biodiversity. However, the potential application of existing national datasets to the assessment of county and sub county-scale trends appears to offer both a more sustainable and statistically powerful approach. This potential should be fully explored as a priority before further development of a field survey approach is undertaken, and it is recommended that practitioners seek to gain knowledge and understanding of the application of these techniques.

As a result of networks formed through the development of this project, Kent Wildlife Trust was invited to become a partner in a National Environment Research Council-funded Knowledge Exchange Fellowship led by The Centre for Ecology and Hydrology. This project aims to translate recent methodological advances in biodiversity monitoring and analysis detailed in Chapter 7 into a form that is directly accessible to data holders, land managers, policy makers and conservation practitioners. This will be achieved through a two-way knowledge flow: co-design, co-development and co-delivery with key stakeholders and representatives of the conservation community across the UK. This may include user narrative documentation or digital tools for the sharing of data and data analysis workflows. Once developed, these products will be promoted to a large audience of stakeholders through a series of workshops and events.

## Ecosystem Function

The insect monitoring approach tested in Chapter 8 quantified change in the abundance of invertebrates against baseline data that exists for the whole of the UK. The approach has the potential to add to the growing body of evidence for significant invertebrate declines in the UK and provides a metric of the functional provision by invertebrates within ecosystems. The results of the pilot survey conducted by the project attracted national and international attention, with 55 pieces of coverage with an estimated potential reach of 271 million world-wide. The mobile app. developed as part of the legacy of this project has national, and potential international application. Kent Wildlife Trust in partnership with Gwent, Essex, and Somerset Wildlife Trusts, BugLife, and with support of the RSPB, launched a national citizen science survey in 2021. This has again attracted significant national media attention and is attracting large numbers of participants. Over 4000 users downloaded the app. nationally in the first week of launch. The anticipated volume of data that will be gathered will allow comprehensive long-term monitoring of general insect abundance across the UK for the first time. While a need for further development to fully realise the potential of the approach is recognised, it offers a significant opportunity for other organisations to be involved and contribute to its success and relevance. The assessment of the plethora of ecosystem functions more widely is a key area in need of development and should form part of any toolkit in the assessment of landscape-scale outcomes, including within Local Nature Recovery Strategies and the wider Nature Recovery Network.

# The Evidence Emergency

The 2019 State of Nature Report[3] reiterated that biodiversity declines are continuing and may in some cases be accelerating. Extinction rates are an order of magnitude above background rates and must be slowed if we are to avoid a sixth mass extinction that could undermine ecosystem functioning that supports the survival of our species. Whilst conservation efforts over the last century have slowed biodiversity declines and saved species from extinction, they have not succeeded in the ultimate goal of halting biodiversity loss. Because of this, business as normal is not an option for conservation organisations. It is possible to halt and reverse biodiversity declines but only if we change some key aspects of our approach to conservation. One critical change is a significant operational and cultural shift in the quantity and quality of conservation evidence collected and in how this informs decision-making, reflected in Kent Wildlife Trusts development of the Nature's Sure Connected project. It was conceived on the basis that while the Lawton review instigated a shift towards landscape-scale action, and while the principles have been widely applied, the monitoring of outcomes is often insufficient to understand impact. Too few Wildlife Trusts have the scientific systems and skills in place to integrate evidence into practice. As a result, there is a risk that Wildlife Trusts are allocating resources to practices that have little or no benefit for wildlife, or indeed have detrimental effects. Wildlife Trusts will not always get it right, but it is important that we can collectively learn from our mistakes. However, an inconsistency of monitoring effort and a lack of standardised protocols limit our ability to do this.

As a result of networks formed through the development of this project, Kent Wildlife Trust is now working in partnership with Gloucestershire Wildlife Trust and Sheffield and Rotherham Wildlife Trust to develop the Evidence Emergency project to disseminate learning from collective experience, with the overall aim of creating a long-term change programme that leads to all Wildlife Trusts being able to access rigorous, standardised evidence protocols and with the movement being recognised as leaders in evidence-led conservation. Kent, Gloucestershire and Sheffield and Rotherham Wildlife Trusts all have dedicated evidence teams containing considerable experience gained from working in academia, statutory agencies, local government, the private sector and within Wildlife Trusts. Gloucestershire Wildlife Trust has helped to develop the Nature Recovery Network handbook and a standardised habitat condition monitoring approach, and Sheffield and Rotherham Wildlife Trust has developed a robust data management system. All three Wildlife Trusts have considerable experience of working with evidence volunteers. It is recognised that other Trusts have knowledge and methods that would make a valuable contribution to this work, and to date twelve further Trusts have expressed an interest in participating in this work, which will collectively establish monitoring frameworks and protocols more widely within the Wildlife Trust movement, informed in part by the outputs of Nature's Sure Connected.

# Data science and GIS skills in conservation

The lack of evidence for conservation programmes can, in part, be ascribed to the lack of data scientists within the sector. There are a significant number of skilled field surveyors and ecologists, and therefore a large potential for the generation of monitoring data. However, many organisations lack the expertise to manage and analyse data efficiently. Local Environmental Record Centres fill part of this gap, however, they are often underfunded and act as a repository of data, rather than being involved in the survey design and data analysis for specific objectives outside of contracted work programmes. Conservation organisations are beginning to act on this discrepancy and are creating data science and GIS roles, which again fill part of the void, but the GIS element is often just the tip of the iceberg, with this role also responsible for data management, survey design, data visualisation and reporting. For the evidence crisis to be rectified, a higher number of data science roles are required across multiple organisations, so that the conservation sector can benefit from advances in technology (for example recording apps for both surveyors and citizen scientists), remote sensing (with increasing availability of open source, high resolution datasets such as the Environment Agency LiDAR survey), to facilitate the automation of the often-repetitive day to day processing of ecological data tasks, and to utilise the efficiencies and statistical power offered by programming and data science skill sets.

[3] *Hayhow DB, Eaton MA, Stanbury AJ, Burns F, Kirby WB, Bailey N, Beckmann B, Bedford J, Boersch-Supan PH, Coomber F, Dennis EB, Dolman SJ, Dunn E, Hall J, Harrower C, Hatfield JH, Hawley J, Haysom K, Hughes J, Johns DG, Mathews F, McQuatters-Gollop A, Noble DG, Outhwaite CL, Pearce-Higgins JW, Pescott OL, Powney GD and Symes N (2019) The State of Nature 2019. The State of Nature partnership.*





# Conservation Evidence

Further to Kent Wildlife Trust gaining accreditation as a Conservation Evidence Champion though resources provided by this project, legacy resulting from a partnership working agreement with Conservation Evidence includes Kent Wildlife Trust taking a joint lead role in chairing the *Evidence in Conservation Practice Working Group*, a group of global conservation practitioners and funders working to better integrate evidence use in conservation funding and practice, and contributing to a number of initiatives to better integrate evidence use in conservation practice:

- Effectively integrating experiments into conservation practice[4]
- Improving conservation effectiveness through the routine testing of management interventions[5].
- Scaling up and delivering effective conservation practice[6]
- Planning practical evidence-based decision making within time constraints[7]
- A practical tool to combine diverse forms of evidence for rapid, systematic, and transparent evidence-based conservation decisions[8]
- Embracing and learning from failure in conservation[9]

*The Evidence in Conservation Practice Working Group* is now focused on sub-groups established to develop solutions for 1) Ways for practitioners to share experience and results outside of peer-review, 2) Frameworks to incorporate evidence into planning and monitoring and evaluation, and 3) Platforms for better communication and collaboration between scientists and practitioners.

[4] *Ockendon, N., Amano, T., Cadotte, M., Thornton, A., Tinsley-Marshall, P., Sutherland, W. J. (In press) Effectively integrating experiments into conservation practice. Ecological Solutions and Evidence.*
[5] *Tinsley-Marshall, P. Downey, H., Adum, G. Al-Fulai, N., Bourn, N. A. D., Brotherton, P N. M., Frick, W. F., Hancock, M. H., Hellon, J., Hudson, M. A., Kortland, K., Mastro, K., McNicol, C. M., McPherson, T., Mickleburgh, S., O'Brien, D., Ockendon, N., Paterson, S., Payne, C. J., Parks, D., Schofield, H., Watuwa, J., Wormald, K., Wilkinson, J., Wilson, J. D., Nichols, C. P., Pimm, S. L., & Sutherland, W. J. (Submitted) Improving conservation effectiveness through the routine testing of management interventions.*
[6] *Tinsley-Marshall, P., Parks, D., Miller, F., Downey, H., Wilson, J., Adum, G., Al-Fulaij, N., Becker, H., Addison, P. F. E., Bourn, N., Frick, W. F., Gumal, M., Hitchcock, G., Kowalska, A., Mastro, K., McIntosh, E. J., McNicol, C., Martins, D. J., Maunder, M., McPherson, T., Mickleburgh, S., Nichols, C. P., O'Brien, D., Ockendon, N., Paterson, S., Rodríguez, J. P., Wilkinson, J., Wilson, J. D., Wormald, K., Zurita, P., Sutherland, W. J. (Submitted) Scaling up and delivering effective conservation practice.*
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## The State of Nature in Kent

Kent Wildlife Trust have been commissioned by the Kent Nature Partnership to produce the State of Nature in Kent 2021 report. This will provide a new and refreshed perspective on how biodiversity is faring in Kent and will begin to provide a reporting mechanism for the new Kent Biodiversity Strategy and to demonstrate the outcomes of collective conservation action at a county-scale. It will build on the existing evidence base by drawing together information on the area of land managed positively for wildlife and habitat connectivity using the approaches developed by the Nature's Sure Connected project. It will deliver a stronger evidence base that will provide an enhanced mechanism for representing the environment in decision making and risk management, strengthen the basis for advocacy and funding, align with regional reporting (such as the national State of Nature report) and continue to develop an ongoing monitoring framework that provides better trend evidence for conservation outcomes in the county.

## The Nature Recovery Network and Local Nature Recovery Strategies

Local Nature Recovery Strategies (LNRS) are a flagship measure in the Environment Bill. These are plans that will help drive more coordinated, practical, focussed action and target investment to help nature and people flourish together, whilst delivering wider nature-based environmental benefits. They will consist of:

- A Statement of Biodiversity Priorities, which reflect stakeholder priorities for environmental outcomes, and the actions that need to be undertaken to achieve these outcomes.
- A Local Habitat Map, which will identify the existing distribution of habitats and the location of areas already important for biodiversity, overlaid by locations considered suitable for delivering the outcomes and actions identified by stakeholders.

The strategies will be a statutory requirement of the upcoming Environment Bill. This means that local councils will be required to develop a LNRS when the bill becomes law, and LNRSs at a county-scale will collectively come together to form a Nature Recovery Network for England. Councils will be required to report on progress on the LNRS every five years. Kent Wildlife Trust is assisting in the coordination, development and delivery of the LNRS for Kent, presenting an opportunity to embed the learning from this project in the establishment of an effective monitoring programme.





## Acknowledgments

We thank the technical advisory group and project steering group for technical support, guidance and direction. We are very grateful for the contribution of the stakeholders listed overleaf to the development of the project. We are also very grateful to the following for their support with the following aspects of the project. **Chapter 4:** Henri Brocklebank (Sussex Wildlife Trust), Andy Fairbairn (Berkshire, Buckinghamshire, & Oxfordshire Wildlife Trust), Catherine McGuire (Hampshire & Isle of Wight Wildlife Trust), Mat Guillard (Surrey Wildlife Trust), Tom Reid (Environment Agency), Clive Steward (Woodland Trust), and Richard Dyer (Southeast Water) provided details of their organisational approaches to recording the area of land managed positively for conservation. Tony Witts (Kent and Medway Biological Records Centre) developed, hosts and updates the Kent Conservation Landscape Tool. **Chapter 5:** Dr Ben Evans (Department of Geography, University of Cambridge) provided assistance in processing RedEdge MX multispectral .tif images into an orthomosaic. **Chapter 6:** Ben Siggary and Mat Guillard (Surrey Wildlife Trust) provided support and advice on using Circuitscape. Mike Phillips (Kent Reptile and Amphibian Group) and Mike Easterbrook (Butterfly Conservation, Kent and Southeast London Branch) provided advice on species parameters to inform connectivity models. **Chapter 7:** Simon Pickles (North and East Yorkshire Ecological Data Network), David Roy (UK Centre for Ecology and Hydrology), Rob Robinson and Simon Gillings (British Trust for Ornithology) provided useful insight into survey effort required at national and sub-national scales to make comparative species trend analysis with equivalent confidence. Rory Harding (Kent Wildlife Trust), and the members of the Upper Beult Farmer Cluster provided support in designing and delivering the species distribution surveys. **Chapter 8:** We thank the Royal Society for the Protection of Birds (RSPB), particularly Richard Bradbury, Richard Bashford and Guy Anderson, for facilitating our use of the 'splatometer' method, helpful discussion and providing baseline survey data that supported our analysis. Mick Crawley and Simon Leather provided helpful feedback on the analysis. We are very grateful to all the volunteer citizen scientists who took part in the survey, The Blackpalfrey Motor Club of Kent, Nu Venture, and volunteers who assisted with data entry, and the volunteers who contributed data to the RSPB survey in 2004. We are very grateful to two anonymous donors who enabled the development of the Bugs Matter app. as part of the legacy of this project. We thank Irene Seijo (Seijo Associates) and Sharon Bayne (Blackwood Bayne) for conducting the project evaluation. Lastly, we thank the National Lottery Heritage Fund for the grant award that enabled us to carry out this project.

# Stakeholders

**Stakeholders whose contributions shaped the development of the project through responses to the questionnaire consultation and/or attendance at workshops.**

| Name | Organisation | Position |
|---|---|---|
| Alison Ruyter | Kent Wildlife Trust | Area Manager, Estates Team |
| Amelia Airey | Surrey Biodiversity Information Centre | Data Officer |
| Andy Willmore | Kent Wildlife Trust | Sevenoaks Greensand Commons Project Manager |
| Barrie Neaves | Environment Agency | Catchment Co-ordinator, East Kent |
| Ben Siggery | Surrey Wildlife Trust | GIS Analyst |
| Bex Cartwright | Bumblebee Conservation | Conservation Officer |
| Bryony Chapman | Kent Wildlife Trust | Wilder Seas Manager |
| Camilla Blackburn | Kent Wildlife Trust | Ecological Consultancy Officer |
| Chloe Edwards | Kent Wildlife Trust | Head of Wilder Landscapes |
| Chris Talbot | Warwickshire Wildlife Trust | Biodiversity Manager |
| Clare Russell | Kent Wildlife Trust | Sevenoaks Greensand Commons Conservation and Access Project Officer |
| Clive Steward | The Woodland Trust | Site Manager |
| Debbie Lewis | Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust | Ecology Manager |
| Diana Tixi | Natural Resources Institute, University of Greenwich | PhD candidate |
| Dr Bob Smith | School of Anthropology and Conservation, University of Kent | Director, Durrell Institute of Conservation and Ecology |
| Emma Lansdell | Bumblebee Conservation | Making a Buzz for the Coast - Project Manager |
| Eric Heath | Avon Wildlife Trust | Head of Land Management |
| Geoff Smith | Specto Natura | Director |
| Gerry Sherwin | High Weald AONB Unit | Business Manager |
| Jeremy Haggar | Department of Agriculture, Health and Environment, University of Greenwich | Professor of Agroecology |
| Jeremy Matthews | Environment Agency | Fisheries, Biodiversity and Geomorphology Officer |
| John Bangay | Butterfly Conservation, Kent & Southeast London Branch | Data Handling Improvement Project |
| John Puckett | Kent Bat Group | Chair |
| John Young | Kent Mammal Group | |
| Josh Hellon | BCN Wildlife Trust | Monitoring & Research Manager |
| Joyce Pitt | Freelance | Botanist and Mycologist |
| Kate Doyle | 2Excel geo | Geospatial Developer |
| Katherine Hawkins | Royal Society of Wildlife Trusts | Senior Living Landscape Officer |
| Keith Kirby | Oxford University | Visiting Researcher, Dept of Plant Sciences |





| Name | Organisation | Position |
|---|---|---|
| Laura Jones | Environment Agency | Catchment Coordinator – Rother, Ravensbourne and Marsh Dykes |
| Laurie Jackson | Buglife | Farm Pollinator and Wildlife Advisor |
| Lucy Breeze | Kent Environment Strategy Manager | Kent County Council |
| Mark Pritchard | Medway Valley Countryside Partnership | Manager |
| Martin Hügi | Woodland Trust | Outreach Manager |
| Mat Guilliatt | Surrey Wildlife Trust | GIS and Data Manager |
| Mathew Frith | London Wildlife Trust | Director of Conservation |
| Matt Hayes | Kent Wildlife Trust | Area Manager, Estates |
| Matt Jones | Norfolk Wildlife Trust | Living Landscape Officer |
| Mike Waite | Surrey Wildlife Trust | Living Landscapes Manager (Strategic) |
| Moragh Stirling | South East Rivers Trust | Catchment Officer |
| Nathan Jones | Butterfly Conservation, Kent & South East London Branch | Chair |
| Nick Sangster | Kent High Weald Partnership | Partnership Manager |
| Paul Hyde | Natural England Kent Team | Lead Advisor |
| Pete Tomlin | Sheffield Wildlife Trust | Senior Data Management & Monitoring Officer |
| Peter Dear | National Trust | Lead Ranger, Sissinghurst Portfolio |
| Phil Williams | Natural England | Conservation Advisor, Kent Team |
| Richard Dyer | South East Water | Biodiversity Lead |
| Richard Haynes | White Cliffs Countryside Partnership | Partnership Manager |
| Rosie Bleet | Buglife | Shrill Carder Bee Project Officer, Back from the Brink |
| Samuel Durham | Lloyd Bore Ltd | Head of Ecology |
| Sarah E J Arnold | Kent Field Club & Natural Resources Institute, University of Greenwich | Behavioural Entomologist |
| Simon Pickles | North and East Yorkshire Ecological Data Centre | Director |
| Stan Smith | Kent Wildlife Trust | Wilder Landscapes Manager |
| Steve Headley | Kent Mammal Group | County Mammal Recorder |
| Steve Masters | Dorset Wildlife Trust | Reserves and Living Landscapes Evidence Officer |
| Steve Weeks | Kent Wildlife Trust | Area Manager, Estates |
| Sue Buckingham | Botanical Society of the British Isles | East Kent Plant Recorder |
| Tim Owen | Kent Downs Area of Outstanding Natural Beauty Unit | Partnership Officer |
| Tom Hayward | London Wildlife Trust | Reserves Manager |

Nature's Sure Connected

A practical framework and guidance for evidencing landscape-scale outcomes of landscape-scale conservation.